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User's Manual First Edition

GEOTRACK and GEOPLOT,
STRESS, BEARING and COMPARE
(Subgrade Stress Analysis and
(Bearing Capacity)

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by

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University of Saskatchewan

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The contents of this report reflect the current views of the research team at the University of Saskatchewan and not necessarily the official views or opinions of Canadian National Railways, Canadian Pacific Railways, or the Transportation Development Centre of Transport Canada.

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16. Abstract

This report contains the user's manuals for the five computer programs used to develop the bearing capacity design charts presented in the final report.

The computer program **GEOTRACK** was purchased for use in a bearing capacity approach to railway subgrade design. A post-processing package **GEOPLOT** was developed to produce graphic output for all of the GEOTRACK output which can be generated. The GEOTRACK and GEOPLOT computer programs can be used independently of the other computer programs to model the stress distribution beneath a track structure.

The **STRESS** computer program was written to perform the averaging of the GEOTRACK stress distributions such that a unique value would be available to represent the stresses below the track system for any given loading configuration and soil conditions. The computer program **BEARING** was developed to compute the bearing capacity of the subgrade system from parameters entered interactively by the user.

Averaged stress distributions computed by the program STRESS can be compared to bearing capacities computed by the program BEARING through use of the program **COMPARE**.

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16. Résumé

Ce rapport renferme les manuels de l'utilisateur relatifs aux cinq programmes utilisés aux fins du calcul des courbes de portance présentées dans le rapport final.

Le programme informatique appelé GEOTRACK a été acheté à l'appui de la méthode de calcul de la stabilité d'une plate-forme ferroviaire, axée sur la portance des sols supports. Un progiciel de post-traitement appelé GEOPLOT a été réalisé et permet de mettre sous forme graphique les données à la sortie du programme GEOTRACK. Ces deux programmes peuvent être utilisés séparément des autres programmes pour modéliser la distribution des contraintes s'exerçant sur un sol support de voie ferrée.

Un programme informatique appelé STRESS a été rédigé pour effectuer le moyennage des distributions de contraintes. La valeur ainsi obtenue représente la contrainte moyenne résultant d'un régime de charge et de caractéristiques mécaniques de sol particuliers. Le programme BEARING permet de calculer la portance du sol support à partir des paramètres introduits interactivement par l'utilisateur.

Enfin, le programme COMPARE permet de comparer les résultats du programme STRESS à ceux du programme BEARING.

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USER'S MANUAL FIRST EDITION

GEOTRACK AND GEOPLOT STRESS, BEARING AND COMPARE
(SUBGRADES STESS ANALYSIS AND BEARING CAPACITY)

Page No.

1.0 INTRODUCTION 1

2.0 USER'S MANUAL FOR THE GEOTRACK COMPUTER PROGRAM 6
- 2.1 Introduction to the GEOTRACK Computer Model 6
- 2.2 Description of the GEOTRACK Computer Model 7
- 2.3 Input Data Description 18
- 2.4 Typical GEOTRACK Output 42
- 2.5 Use of the GEOTRACK Computer Program for the Stress Analysis Side of a Bearing Capacity Design Approach 53

3.0 USER'S MANUAL FOR THE GEOPLOT COMPUTER PROGRAM 81
- 3.1 Introduction to the GEOPLOT Graphics Program 81
- 3.2 Description of the GEOPLOT Graphics Package 82
- 3.3 Screen Displays and User Response 87
- 3.4 Typical Output 100

4.0 USER'S MANUAL FOR THE STRESS COMPUTER PROGRAM 123
- 4.1 Introduction to the STRESS Computer Program 123
- 4.2 Description of the STRESS Computer Program 124
- 4.3 Screen Displays and User Responses 130
- 4.4 Typical Output Files 133

5.0 USER'S MANUAL FOR THE BEARING COMPUTER PROGAM 139
- 5.1 Introduction to the BEARING Computer Program 139
- 5.2 Description of the BEARING Computer Program 141
- 5.3 Screen Displays and User Responses 148
- 5.4 Typical Output Files 157

6.0 USER'S MANUAL FOR THE COMPARE COMPUTER PROGRAM 161
- 6.1 Introduction to the COMPARE Computer Program 161
- 6.2 Description of the COMPARE Computer Program 161
- 6.3 Screen Displays and User Responses 164
- 6.4 Typical Results 167

7.0 CONCLUSIONS 170

LIST OF REFERENCES 171

APPENDIX A 172

LIST OF FIGURES

		Page No.
Figure 1.1	Flow Chart of Computer Programs	2
Figure 2.1	Components of Conventional Track Structure	8
Figure 2.2	Forces and Elements in the GEOTRACK Model	9
Figure 2.3	Tie Numbering System	11
Figure 2.4	Load Spacings	12
Figure 2.5	Tie Segment Locations	14
Figure 2.6	Typical Offset Locations	17
Figure 2.7	Division of Roadbed Layers	21
Figure 2.8	Resilient Modulus vs Deviator Stress for Cohesive Soils (9)	28
Figure 3.1	General Algorithm for the GEOPLOT Computer Program	83
Figure 3.2	Longitudinal View of the Track System showing the Geometry Parallel to the Track	85
Figure 3.3	Cross-sectional View Perpendicular to the Track	86
Figure 3.4	Using VIEW to View a GEOPLOT File	92
Figure 3.5	GEOPLOT Vertical Stress Perpendicular to the Track	101
Figure 3.6	GEOPLOT Vertical Stress Parallel to the Track	102
Figure 3.7	GEOPLOT Horizontal Stress in the Y-direction Parallel to the Track	103
Figure 3.8	GEOPLOT Soil Vertical Displacement	104
Figure 3.9	GEOPLOT Rail Deflection	105
Figure 3.10	GEOPLOT Rail-Seat Reaction	106
Figure 3.11	GEOPLOT Tie Deflection	107
Figure 3.12	GEOPLOT Tie Center Bending Moment	108
Figure 3.13	GEOPLOT Tie Rail-Seat Bending Moment	109

Figure 3.14 GEOPLOT Rail Bending Moment 110
Figure 3.15 GEOPLOT Tie-Soil Reaction 111
Figure 3.16 GEOPLOT Tie Segment Deflection 112
Figure 3.17 GEOPLOT Maximum Principal Stress Parallel to the Track 113
Figure 3.18 GEOPLOT Maximum Principal Stress Perpendicular to the Track 114
Figure 3.19 GEOPLOT Directional Cosine for the Maximum Principal Stress in the Z-direct 115
Figure 3.20 GEOPLOT Deviator Stress 116
Figure 3.21 GEOPLOT Bulk Stress 117
Figure 3.22 GEOPLOT Geostatic Vertical Stress 118
Figure 3.23 GEOPLOT Maximum p 119
Figure 4.1 General Algorithm for STRESS Computer Program 125
Figure 4.2 Option 1 "Stress Averaging Technique" 126
Figure 4.3 Option 2 "Stress Averaging Technique" 127
Figure 4.4 Option 3 "Stress Averaging Technique" 128
Figure 4.5 Option 4 "Stress Averaging Technique" 129
Figure 4.6 Option 1 Output from STRESS Program 134
Figure 4.7 Option 2 Output from STRESS Program 135
Figure 4.8 Option 3 Output from STRESS Program 136
Figure 4.9 Option 4 Output from STRESS Program 137
Figure 5.1 General Algorithm for the BEARING Computer Program 140
Figure 5.2 Option 1 "Bearing Capacity Failure Geometry" 142
Figure 5.3 Option 2 "Bearing Capacity Failure Geometry" 143
Figure 5.4 Option 3 "Bearing Capacity Failure Geometry" 144
Figure 5.5 Option 4 "Bearing Capacity Failure Geometry" 145

Figure 5.6 Determination of the Punching Shear Coefficient (Hanna and Meyerhof (3) 146
Figure 5.7 Determination of the Punching Shear Coefficient (Hanna and Meyerhof (3)) 147
Figure 5.8 Bearing Capacity Program Output File 158
Figure 5.9 Bearing Capacity Program Output File 159
Figure 6.1 General Algorithm for COMPARE Computer Program 163
Figure 6.2 COMPARE Program Output File 168
Figure 6.3 COMPARE Program Output File 169

1.0 INTRODUCTION

This report contains the users' manuals for the series of computer programs which were used to develop the bearing capacity design charts, (i.e., the charts presented in the project final report "The Development of Bearing Capacity Design Charts for Track Systems" (1)). Five computer programs were utilized in the chart development, namely: 1) GEOTRACK, 2) GEOPLOT, 3) STRESS, 4) BEARING, and 5) COMPARE. Figure 1.1 illustrates the relationships between the computer programs and the respective generated input and output data.

The flow chart in Figure 1.1 is divided into two sides: 1) the stress analysis portion for the bearing capacity approach to railway subgrade design, and 2) the bearing capacity calculation for the design approach. The two sides to the analysis are used together in a bearing capacity approach to railway design (1).

The computer program GEOTRACK was obtained from Harry Stewart, one of the developers of the GEOTRACK computer program (2), and used in a bearing capacity approach to railway design. A post-processing graphics package, GEOPLOT, was developed to produce graphic output for all of the GEOTRACK output which can be generated. The GEOTRAK and GEOPLOT computer programs can be used independently of the other computer programs for the purposes of modelling the stress distribution beneath a tie-track structure. The use of the GEOTRACK computer program for stress modelling is presented in Section 2 of this document. Specific details regarding the use of the GEOTRACK computer program for the bearing capacity approach are also discussed in Section 2. The users' manual for the GEOPLOT computer program is presented in Section 3.

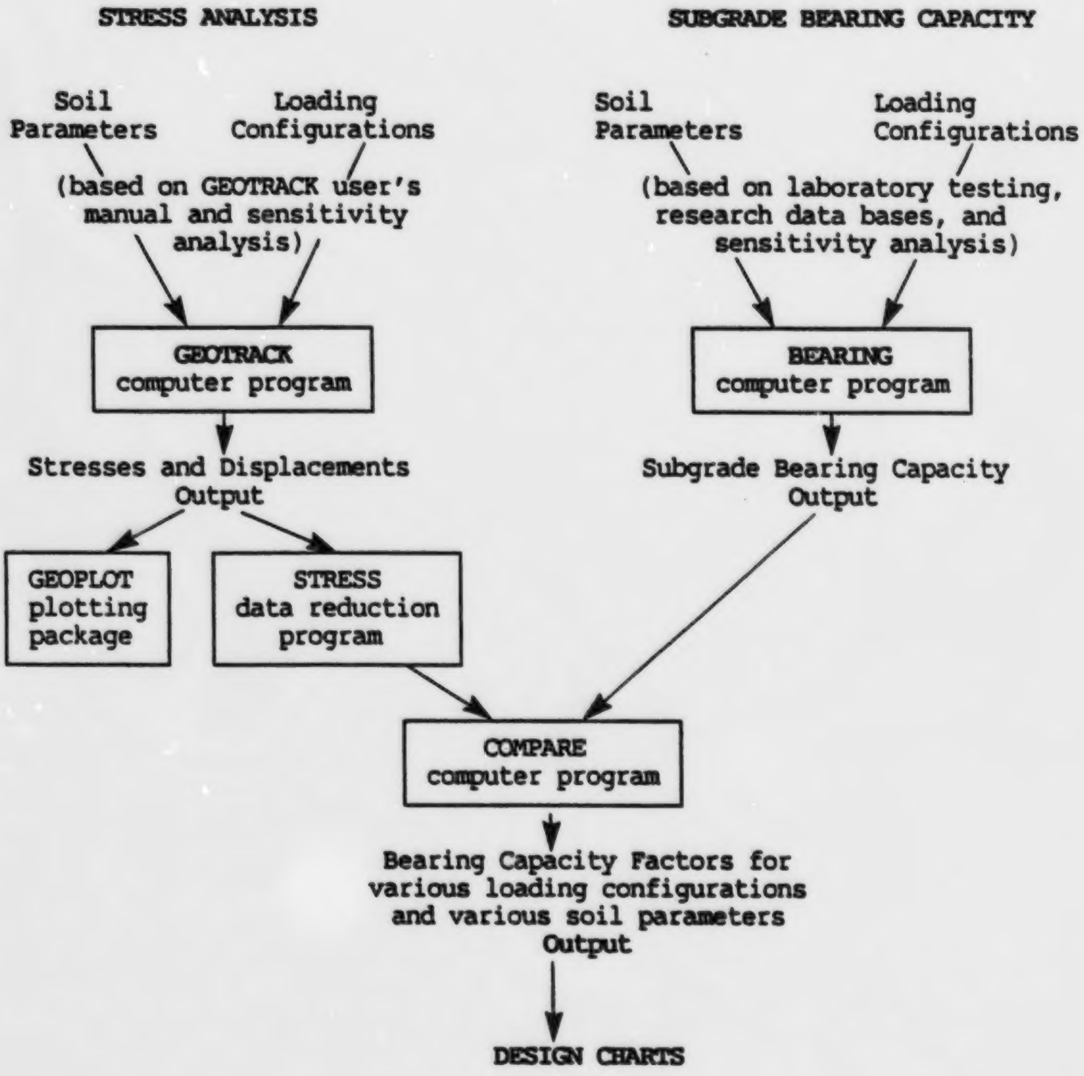

STRESS ANALYSIS
SUBGRADE BEARING CAPACITY
Soil Parameters
Loading Configurations
(based on GEOTRACK user's manual and sensitivity analysis)
Soil Parameters
Loading Configurations
(based on laboratory testing, research data bases, and sensitivity analysis)
GEOTRACK computer program
BEARING computer program
Stresses and Displacements Output
Subgrade Bearing Capacity Output
GEOPLOT plotting package
STRESS data reduction program
COMPARE computer program
Bearing Capacity Factors for various loading configurations and various soil parameters Output
DESIGN CHARTS

Figure 1.1 Flow Chart of Computer Programs

The STRESS computer program was written to perform the averaging of the GEOTRACK stress distributions such that a unique value would be available to represent the stress below the track system for any given loading configuration and soil conditions. The use of the STRESS computer program is limited to the averaging of the stress distributions used in the bearing capacity design approach. The STRESS computer program provides the output stresses which were used to develop the stress charts presented in the body of the final report (i.e., "The Development of Bearing Capacity Design Charts for Track Systems" (1)). STRESS is documented in Section 4.

On the bearing capacity side of Figure 1.1, the computer program, BEARING, calculates the bearing capacity for the subgrade system from parameters entered interactively by the user. The user may request either the Hanna and Meyerhof approach (3) or the Broms approach (4) to be used to calculate the bearing capacity. The computer program, BEARING, may be used independently of the other computer programs to calculate bearing capacity for a track system. Alternatively, the computer program may be used for computing reasonable bearing capacity values for comparison to the averaged stress distributions. Section 5 describes the use of the BEARING computer program.

Averaged stress distributions computed by the program, STRESS, can be compared to reasonable bearing capacities computed by the program, BEARING. This comparison is performed by the program, COMPARE, documented in Section 6. The results of the computer programs, STRESS, BEARING, and COMPARE, were used to develop the bearing capacity factor of safety charts presented in the final report entitled, "The Development of Bearing Capacity Design Charts for Track Systems" (1).

GEOTRACK USER'S MANUAL

2.0 User's Manual for the GEOTRACK Computer Program

Three copies of the GEOTRACK computer program were obtained from Harry E. Stewart, one for use by each of: 1) Canadian National Railways, 2) Canadian Pacific Railways, and 3) the Transportation Development Center. Each copy was provided with a user's manual for the GEOTRACK computer program. The GEOTRACK user's manual, provided by Harry Stewart, has been adapted for inclusion in this report. However, the copies of the GEOTRACK computer program were purchased exclusively for use by CN Rail, CP Rail and the Transportation Development Center and shall not be copied for distribution. Additional copies of the GEOTRACK computer program are available from:

Harry E. Stewart, Ph.D., P.E.
Consultant in Geotechnical Engineering
17 Hunt Grove Road
Ithaca, New York 14850
(607) 539-6189

Following is the adapted version of the GEOTRACK user's manual provided by Harry Stewart. Section numbers and titles have been changed to coincide with the numbering system for this report. In the section describing the GEOTRACK model, the original paragraph order has been changed and the original manual has been supplemented by published literature (2). The final discussion on the GEOTRACK computer program relates to the specific use of the program in a bearing capacity analysis.

2.1 Introduction to the GEOTRACK Computer Model

GEOTRACK is a three-dimensional nonlinear elastic multi-layer model for the analysis of conventional railroad track structures under quasi-static dynamic loadings (2, and 5). The model can analyze up to four superimposed axle loads. The nonlinear stress-dependent soil moduli for the trackbed layers are incorporated using an iterative solution scheme. The problem is solved repeatedly under the full specified loading conditions until the stress-dependent modulus for each layer is consistent with the layer stresses. The number of iterations is selected by the user, but three iterations generally are sufficient to assure convergence of the moduli.

The GEOTRACK model emphasizes the geotechnical aspects of track behaviour. In addition to providing outputs of rail seat load reactions, tie-ballast reactions, and tie and rail deflections, the complete stress tensor, deviator stress, bulk stress, principal stresses and principal stress directions can be computed at specified locations within the trackbed.

2.2 Description of the GEOTRACK Computer Model

The GEOTRACK program is used for analyses of wheel load induced stresses and deformations in a track structure. The track structure consists of rails, ties, and the supporting foundation, as shown in Figure 2.1.

The rails and ties are represented as linear elastic beams with a specified modulus of elasticity, cross-sectional area, and moment of inertia (2). Stress is distributed from the rail to the tie and from the tie to the ballast in the form of concentrated reactions through the tie segements (2). Figure 2.2 provides a pictorial representation of how the model functions.

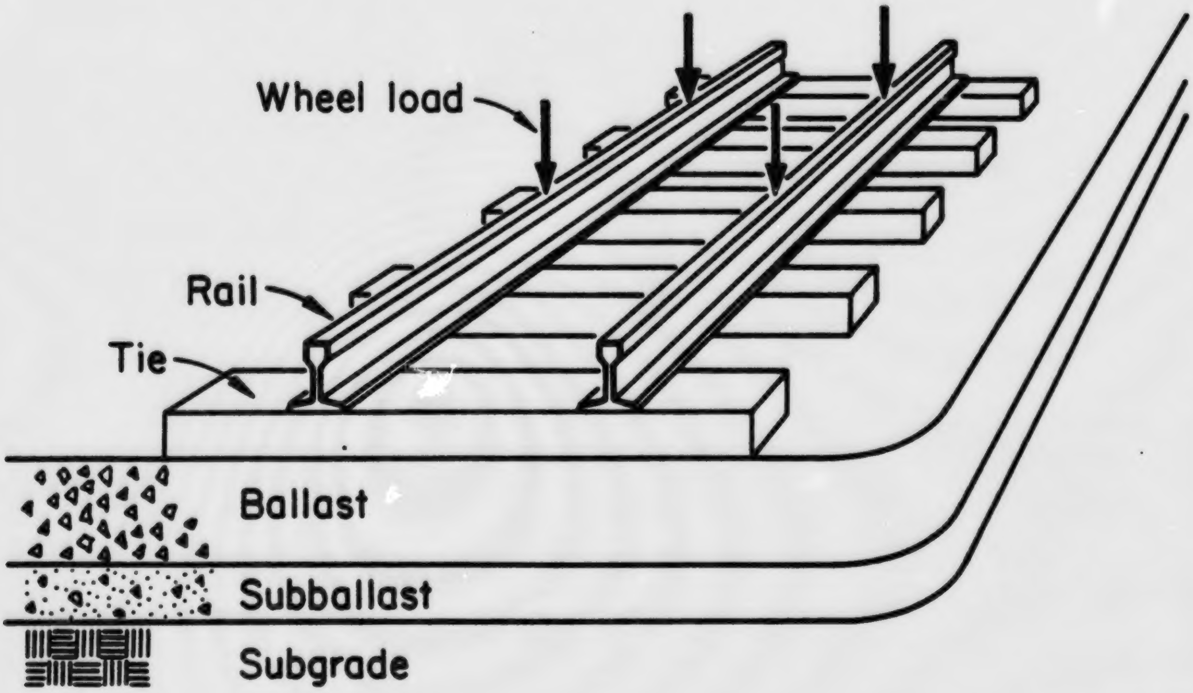

Wheel load
Rail
Tie
Ballast
Subballast
Subgrade

Figure 2.1 Components of Conventional Track Structure

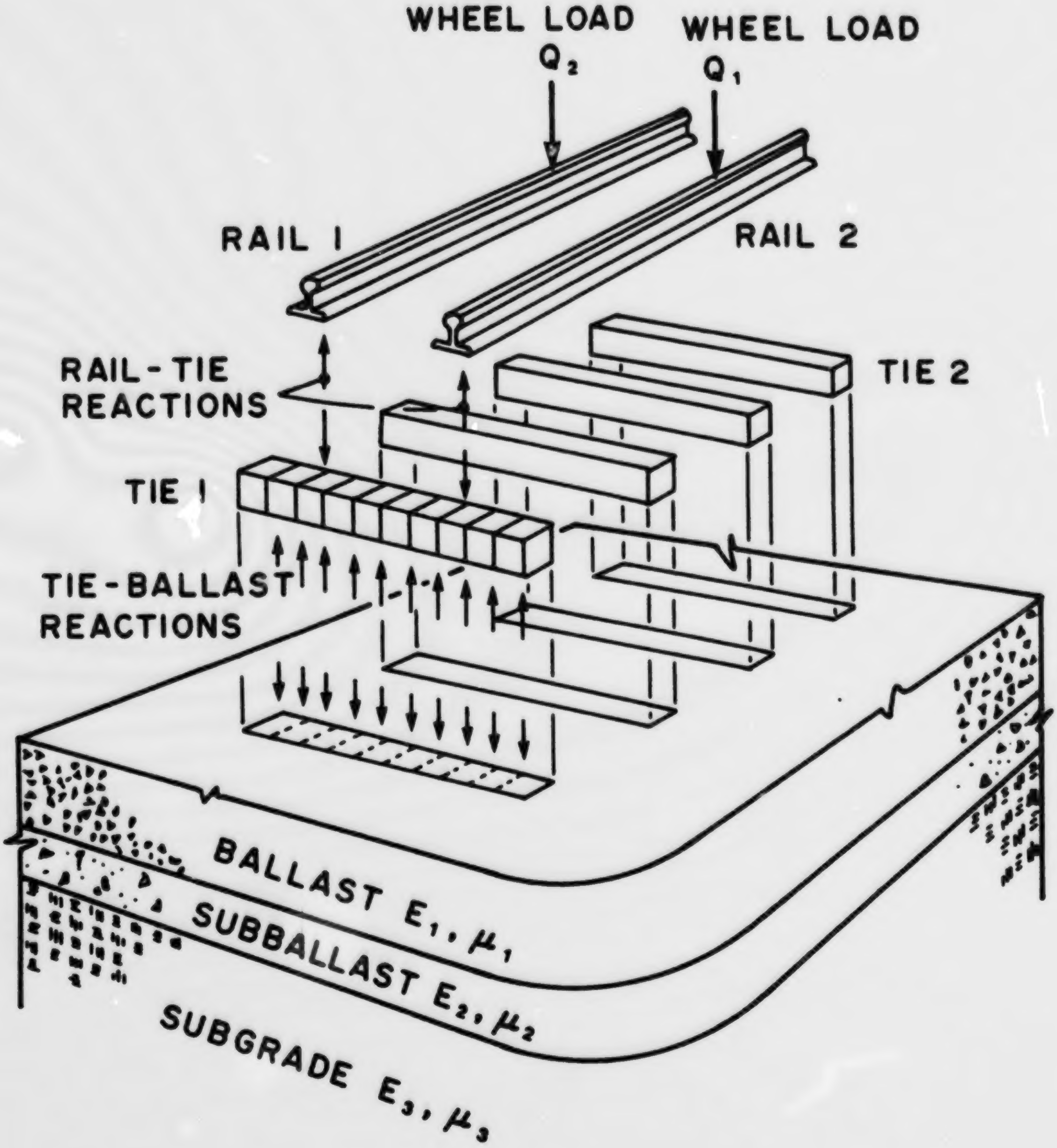

WHEEL LOAD
Q_2
WHEEL LOAD
Q_1
RAIL 1
RAIL 2
RAIL-TIE
REACTIONS
TIE 2
TIE 1
TIE-BALLAST
REACTIONS
BALLAST E_1, μ_1
SUBBALLAST E_2, μ_2
SUBGRADE E_3, μ_3

Figure 2.2 Forces and Elements in the GEOTRACK Model

The ballast, subballast, and subgrade soil are represented as linear elastic layers each specified by a separate modulus of elasticity and Poisson's ratio. All layers are infinite in the horizontal plane and are situated on a half space, which is infinite in the vertical and horizontal directions (2).

The multi-layer system is used to develop stress and displacement influence coefficients. Compatibility of displacements and equilibrium of forces between the bottom of the rail-tie structure and the top of the foundation are then imposed to effect an overall solution to the system. The flexibility matrix for the foundation is combined with the flexibility matrix of the rail-tie system to produce a set of simultaneous equations which are solved for the stresses and displacements at the contact points between the superstructure and the substructure and the stresses and displacements at the desired locations within the layered soil system (2).

For single axle loading, the rails are supported on eleven ties, the load being applied to the center tie. For multiple axle loadings, the additional loads are placed directly over the additional ties. The tie numbering system is shown in Figure 2.3. Since the tie spacings are relatively narrow and the rigidity of the rails is quite high, the differences resulting from a load placed at some location between the supporting ties and a load placed directly over a tie are not significant. If a load must be placed between tie locations, the user may split the load into equivalent loads placed directly over the ties, as shown in Figure 2.4.

Superposition of axle loads is done by solving the problem for a single axle case and summation of the appropriate results. Since the

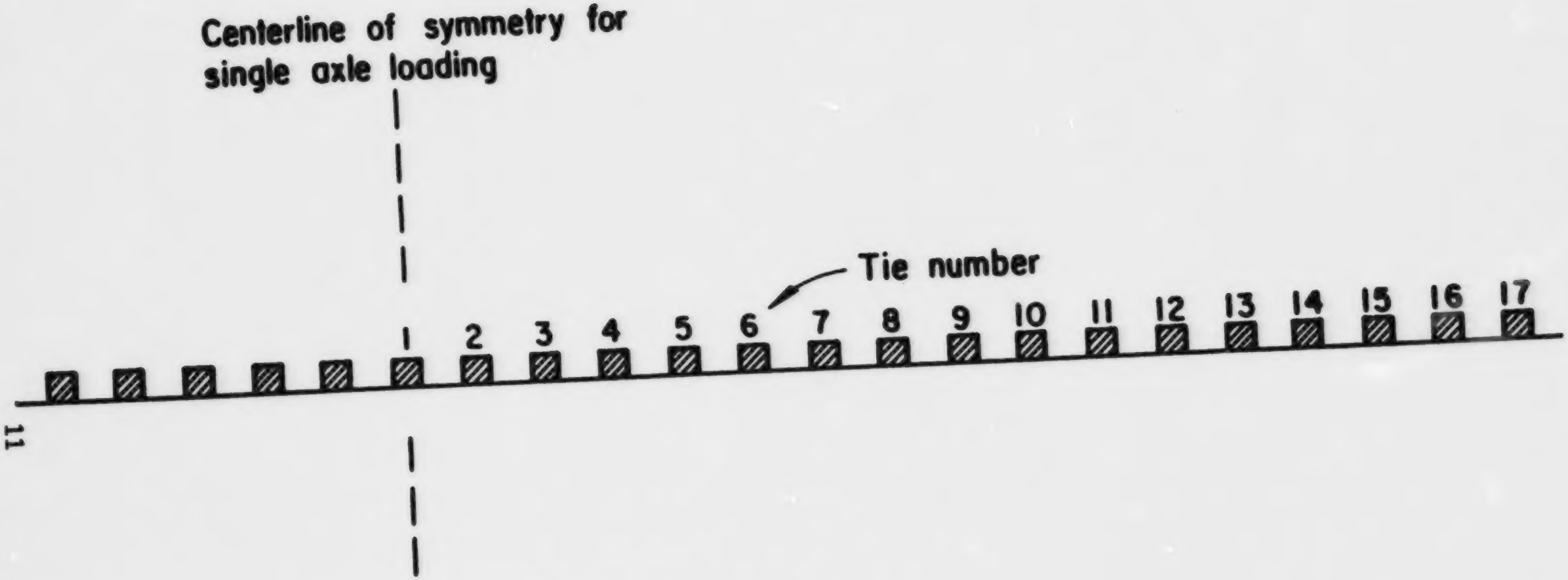
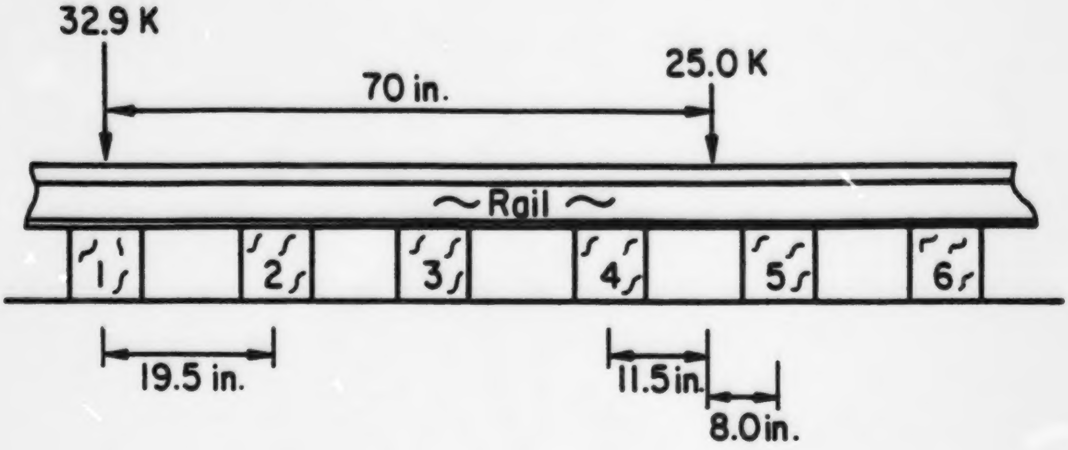

Centerline of symmetry for single axle loading
Tie number
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

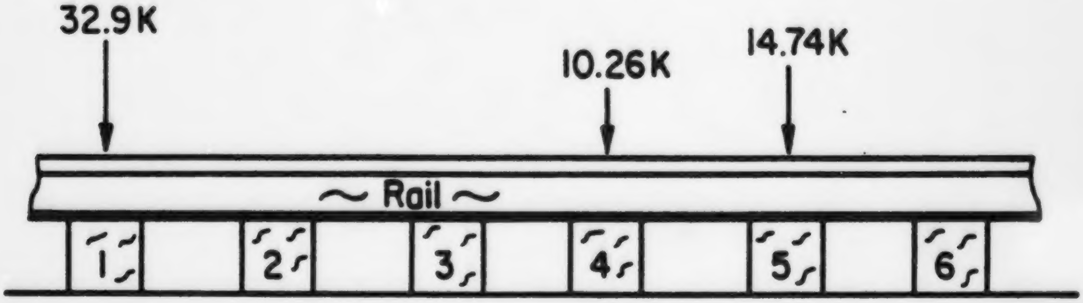
Figure 2.3 Tie Numbering System

a) Original


32.9 K
70 in.
25.0 K
~Rail~
1
2
3
4
5
6
19.5 in.
11.5 in.
8.0 in.

User desires a double axle loading, with unequal axle loads spaced at 70 in. Assume tie spacing = 19.5 in., first wheel load = 32.9 K, second wheel load = 25.0 K, as shown above.

b) Equivalent


32.9K
10.26K
14.74K
~Rail~
1
2
3
4
5
6

Equivalent loads on ties 4 and 5:

at tie 4: P* = 25.0 (8.0/19.5) = 10.26 K
at tie 5: P* = 25.0 (11.5/19.5) = 14.74 K

Input data:

NAXLES = 3

LP(1) = 1	PWHL(1) = 32.9
LP(2) = 4	PWHL(2) = 10.26
LP(3) = 5	PWHL(3) = 14.74

Figure 2.4 Load Spacings

model treats each iteration as a linear elastic problem, unequal axle loads can be superimposed by multiplying the single axle solution by the ratio of axle loads and adding the results.

The GEOTRACK model simulates the ballast, subballast and subgrade as infinite width horizontal layers situated on a semi-infinite half space. Each layer is characterized as an elastic material in which the resilient modulus, Er, is a function of stress state. A weighted average stress in each layer is used to determine the soil modulus for that layer. When superposition of several axle loads is used, the superimposed stresses are used to determine the soil moduli for the next iteration.

The values of resilient Poisson's ratio are assumed to be constant in this program, because the response of the track system is relatively insensitive to variation of the Poisson's ratio. Poisson's ratio generally varies between 0.2 and 0.4 for granular materials such as ballast, and between 0.4 and 0.5 for cohesive subgrades. (Note, however, that Poisson's ratio must be less than 0.5. See Data Entry Type 4.)

The user may specify up to a maximum of five different soil layers to model the roadbed materials. In regions of large stress variations, such as the upper 508 mm (20 in.) of the roadbed, three layers are suggested.

Each tie in the track structure is divided into ten equal segments. The tie segment numbers and locations are shown in Figure 2.5. Because the track loading and track geometry are symmetrical with respect to both the track and tie centerlines, only 1/4 of the total track section needs to be analyzed for single axle

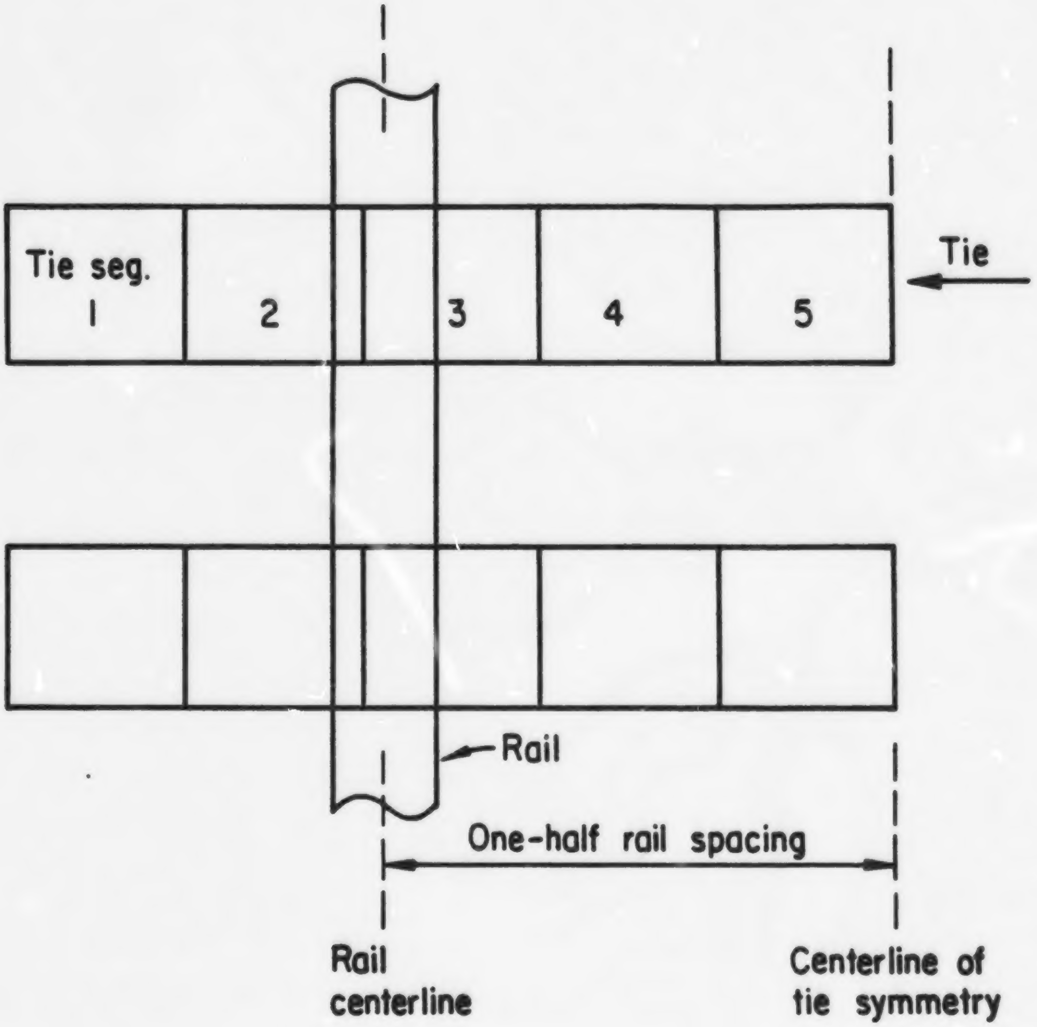

Tie seg.
1
2
3
4
5
Tie
Rail
One-half rail spacing
Rail centerline
Centerline of tie symmetry

Figure 2.5 Tie Segment Locations

loading. When multiple axle loadings are used, the zone of influence for additional loadings is limited to five ties beyond the last loaded tie. By consideration of the symmetry of the loading conditions, the user can derive entire roadbed response from the GEOTRACK output. The standard soil output consists of stresses and displacements at points directly under the center of each tie segment at the specified depths, as well as tie and rail bending moments, rail seat loads, tie-soil reactions, and tie and rail deflections.

The program contains an option that considers tie-ballast separation. Some of the tie-soil reactions on the ties towards the end of the track section (i.e., ties four, five and six, for single axle loading) are often negative, indicating an upward incremental tensile force on the ballast. Since this is not permissible physically, the program contains an option that eliminates these tensile forces. The method for doing this involves modification of the soil and tie flexibility matrix and displacement vector within the portion of the program that solves only for the incremental effects of train loading. The maximum tensile force allowed on any tie segment is limited to the portion of the static weight of the tie and rail that acts on each tie segment. In the model, the static tie weight is distributed uniformly to the tie segments, whereas the static rail weight is distributed such that the rail weight per tie segment is inversely proportional to the distance that the center of the tie segment is from the rail location. The program will successively solve the structural problem and check the individual tie-soil reactions against the static tie segment weights to eliminate large tensile forces.

Since the GEOTRACK model was developed to emphasize the geotechnical aspects of the track, the user may select output of soil stresses in the form of equivalent axisymmetric triaxial stresses. When this option is selected, the geostatic soil stresses resulting from the combined overburden and structural weights are added to the incremental soil stresses. The three-dimensional stress states at points within the foundation are then converted into the triaxial stress states. The geostatic vertical stresses at locations beneath the ties are those caused by the weight of the overlying soil and the weights of the ties and rails. The procedure followed uses the method of stress invariants by matching the octahedral normal and octahedral shear stresses to the conventional constant confining pressure triaxial octahedral normal and octahedral shear stresses. Output of this form consists of equivalent triaxial confining and vertical stresses, as well as p-q values for use in the stress path method. Details of this formulation are given in Reference 5. Appendix A describes the method used to calculate the equivalent triaxial stresses.

An additional modification has been added that can be used to compute the incremental stresses at locations other than those directly beneath the track structure. A typical offset location is shown in Figure 2.6. Up to five depth points for any offset location can be specified. The offset location is adjacent to the center tie. The stresses computed at the offset location are due to a single-axle solution only.

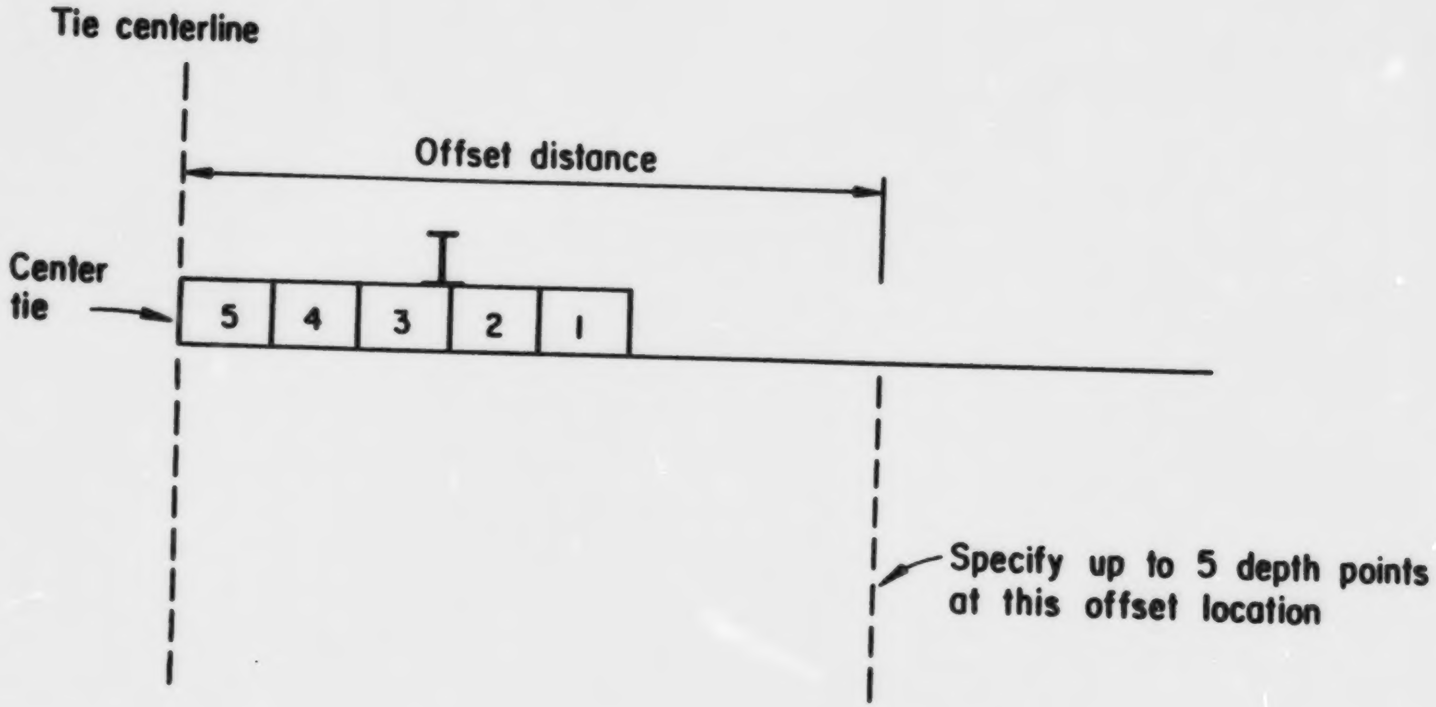

Tie centerline
Offset distance
Center tie
5
4
3
2
1
Specify up to 5 depth points at this offset location

Figure 2.6 Typical Offset Locations

2.3 Input Data Description

Data may be entered through either the keyboard or from a data file. Initial screen prompts and user responses determine the method of data input. The user may select keyboard data input and then save the input in a data file. This option is convenient when several similar computer runs will be done, with only minor differences to the input data for each case. The first data set could be input from the keyboard and saved. The subsequent runs could be made using the input data file after it had been edited to reflect the data modifications.

The computed track responses are saved in a file on the user's disk. The output file name is given by the user, in response to a screen prompt. Following the analysis, the output file can be recalled and viewed on the screen or be printed using the normal operating system procedures. For some output options (ITPRIN = 1 and ITRIAX = 1), the generated output is in a format that is wider than one screen, and wider than an 80-column printer will handle, unless the printer mode is set for 132 characters per line. (See you DOS manual for the necessary printer set-up commands.)

An alternative to printing or viewing the output data is to graph the data using the GEOPLOT post-processing graphics package described in Section 3.

Some of the data is in fixed format, while other data is in free format. For free format, a comma or blank must separate each item. There are 15 Data Entry Types detailed in the following pages. All data input to the GEOTRACK program must be in British Imperial units. However, use of the GEOPLOT graphics program allows the user to plot the GEOTRACK output in either British Imperial or SI units.

1. Data Entry Type 1

```
--------------------------
    TITLE(I), I=1,15
--------------------------
     KEYBOARD:  15A4
    DATA FILE:  15A4
```

TITLE(1).......TITLE(15) = Any set of 60 characters identifying the problem.

2. Data Entry Type 2

```
-------------------------------------------------------
 NS    LACOPT   NITER   INTERF   NOTENS   NOTHER
-------------------------------------------------------
```

KEYBOARD: FREE FORMAT
DATA FILE: FREE FORMAT

i. **NS:** Number of layers into which the roadbed is divided. More than one division could be used for each material. A typical subdivision (as shown in Fig. 2.7) could be two ballast layers, one subballast layer, and two subgrade layers. There should be at least two subgrade layers if nonlinear moduli are used in the subgrade, because of the large variation of moduli with depth resulting from geostatic stress increase. The total number of layers must not be greater than five.

ii. **LACOPT:** An option for computing only the influence coefficients or solving the entire problem.

= 0 Compute only the influence coefficients.
= 1 Compute the influence coefficients and solve the entire track problem.

iii. **NITER:** Number of iterations used to allow the soil moduli used to converge. In most cases, three iterations have been found sufficient for reasonable convergence of moduli. The number of calculation steps through the program is equal to NITER + 1.

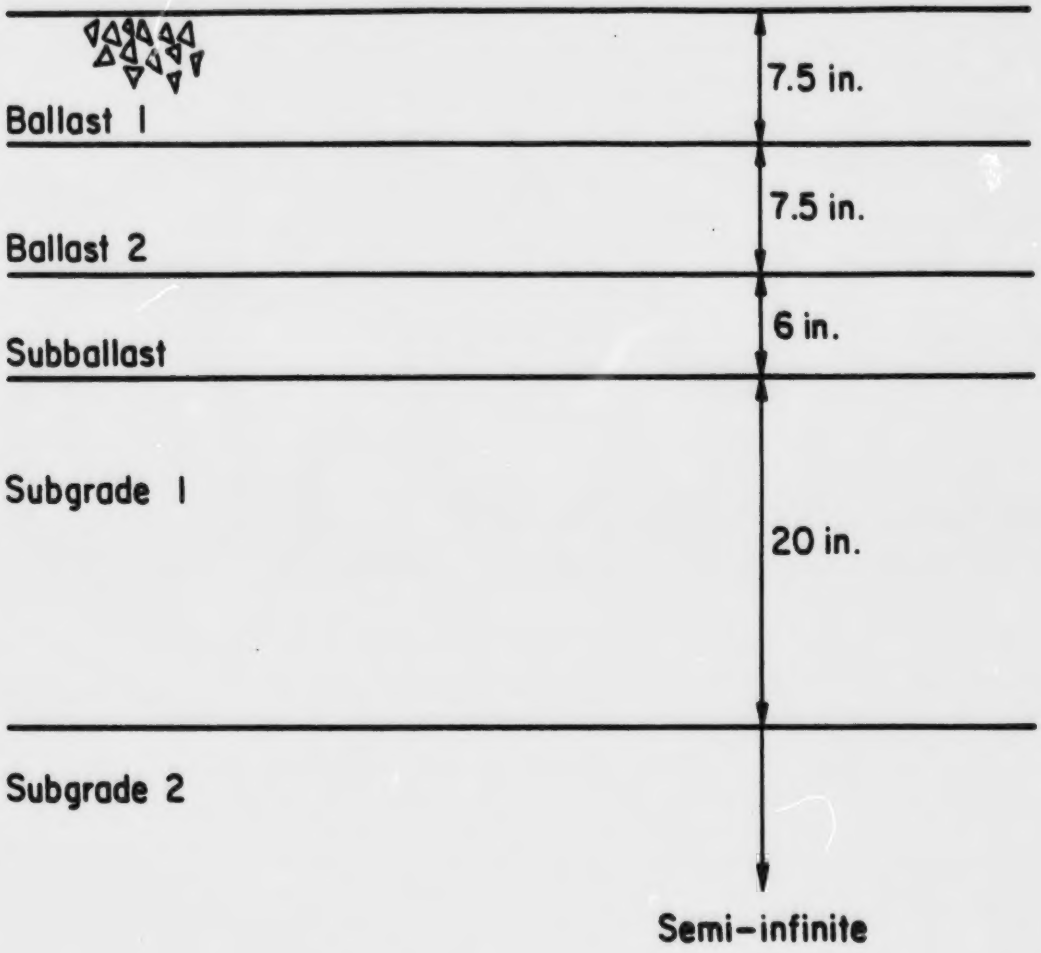

Ballast 1
7.5 in.
Ballast 2
7.5 in.
Subballast
6 in.
Subgrade 1
20 in.
Subgrade 2
Semi-infinite

Figure 2.7 Division of Roadbed Layers

iv. **INTERF:** An option for obtaining stresses and displacements at locations other than at the depths used to determine the stress-dependent moduli. The stress and displacement values provided at the end of the previous iteration are usually those for the mid-depth locations of layers, since layer midpoints generally are used for the computation of average layer moduli. If information is required at other locations, for instance, near the interface of layers, a final calculation is carried out to determine the values at those locations, using the moduli determined in the previous iteration.

= 0 If information is not required at depths other than those used for moduli iterations, or if NITER = 0.

= 1 If information is required at depths other than those used for moduli iterations.

NOTE: If INTERF = 1, Data Entry Types 15 and 16 must be specified.

v. **NOTENS:** An option for limiting the maximum incremental tie/soil tensile forces.

= 0 Do not limit tie/soil tensions.

= 1 Limiting the maximum incremental tensile tie/soil reactions to the static weights assigned to the tie segments.

vi. **NOTHER**: An option for computing stresses at locations adjacent to the track structure.

- = 0 Locations adjacent to the track structure will not be specified.
- = 1 Locations adjacent to the track structure will be specified.

NOTE: If NOTHER = 1, Data Entry Types 18 and 19 must be specified. If both INTERF = 1 and NOTHER = 1, Data Entry Types 15 and 16 must be used, Data Entry Type 17 must be specified as (integer) 9999, and Data Entry Types 18 and 19 must be used. If INTERF = 0 and NOTHER = 1, then only Data Entry Types 18 and 19 must be specified (15, 16 and 17 would not be needed).

3. Data Entry Type 3

```
 ---------------------
  IOPT          ITOPT
 ---------------------
 KEYBOARD:  FREE FORMAT
DATA FILE:  FREE FORMAT
```

i. **IOPT**: Option for printing out the soil influence coefficients.

= 0 Do not print coefficients.
= 1 Print coefficients.

ii. **ITOPT**: Option for printing out computed values for each iteration.

= 0 Print only the results from the final iteration.
= 1 Print the results from all iterations.

4. Data Entry Type 4

```
------------------------------------------------------------------
 E(I) VRAT(I) HH(I) GAMMA(I) KNOT(I) KTYPE(I) KONE(I) KTWO(I)
------------------------------------------------------------------
                     KEYBOARD:  FREE FORMAT
                    DATA FILE:  FREE FORMAT
```

These data entries contain the specific material properties, layer depth and type of nonlinear soil modulus formulation used for each soil layer. The number of lines in this group must be equal to the number of soil layers, NS.

i. E(I): Resilient Young's modulus, E_r, for layer i(psi). Minimum E = 100.1, maximum E = 0.1E30

ii. VRAT(I): Poisson's ratio for layer i. Minimum VRAT = 0.05, maximum VRAT = 0.499.

iii. HH(I): Depth of layer i (in.). Maximum HH = 1000.
<u>NOTE</u>: HH(I) for the last layer must be input as 0.0.

iv. GAMMA(I): Soil unit weight for layer i (lbs/ft^3).

v. KNOT(I): Coefficient of lateral earth pressure for layer i.

vi. **KTYPE(I)**: Type of stress-dependent relationship to use for soil layer i.

= 0 No correction.

$E_r(\text{new}) = E_r(\text{old})$.

= 1 Log-log correction.

$$E_r = P_a K_1 \left(\frac{\theta}{P_a}\right)^{K_2}$$

= 2 Semi-log correction.

$$E_r = P_a \left[K_1 + K_2 \log \left(\frac{\theta}{P_a}\right) \right]$$

= 3 Arithmetic correction.

$$E_r = P_a \left[K_1 + K_2 \left(\frac{\theta}{P_a}\right) \right]$$

= 4 Special experimental correction, only for ballast with Ko > 1.

= 5 For stiff subgrade.

= 6 For medium subgrade.

= 7 For soft subgrade.

= 8 For very soft subgrade.

NOTE: **KTYPE** = 1 to **KTYPE** = 3 are based upon bulk stress formulations. Table 2.1 gives typical coefficients for ballast, subballast, and subgrade materials. For KTYPE = 5 to KTYPE = 8, the correction is based on deviator stress, $\sigma_1 - \sigma_3$, as shown in Fig. 2.8 . The formulations shown in Fig. 2.8 are for cohesive soils.

P_a = Atmospheric pressure = 14.7 psi.

θ = Bulk stress at iteration point in the layer, including geostatic stress.

$\sigma_1 - \sigma_3$ = Deviator stress based upon equivalent triaxial states.

Table 2.1 Resilient Modulus Coefficients Based Upon Bulk Stress

Model	K_1	K_2	Ref.
a) Ballast			
$E_r = P_a K_1 (\frac{\theta}{P_a})^{K_2}$	1569	0.535	5
	1058	0.593	7
	2067	0.509	8
$E_r = P_a[K_1 + K_2 \log(\frac{\theta}{P_a})]$	1023	2147	7
$E_r = P_a[K_1 + K_2(\frac{\theta}{P_a})]$	1543	425	5
	659	449	7
b) Subballast (FAST Material)			
$E_r = P_a K_1 (\frac{\theta}{P_a})^{K_2}$	941	0.687	8
c) Subgrade (FAST Material USCS = SM)			
$E_r = P_a K_1 (\frac{\theta}{P_a})^{K_2}$	877	1.10	7
	654	1.08	8

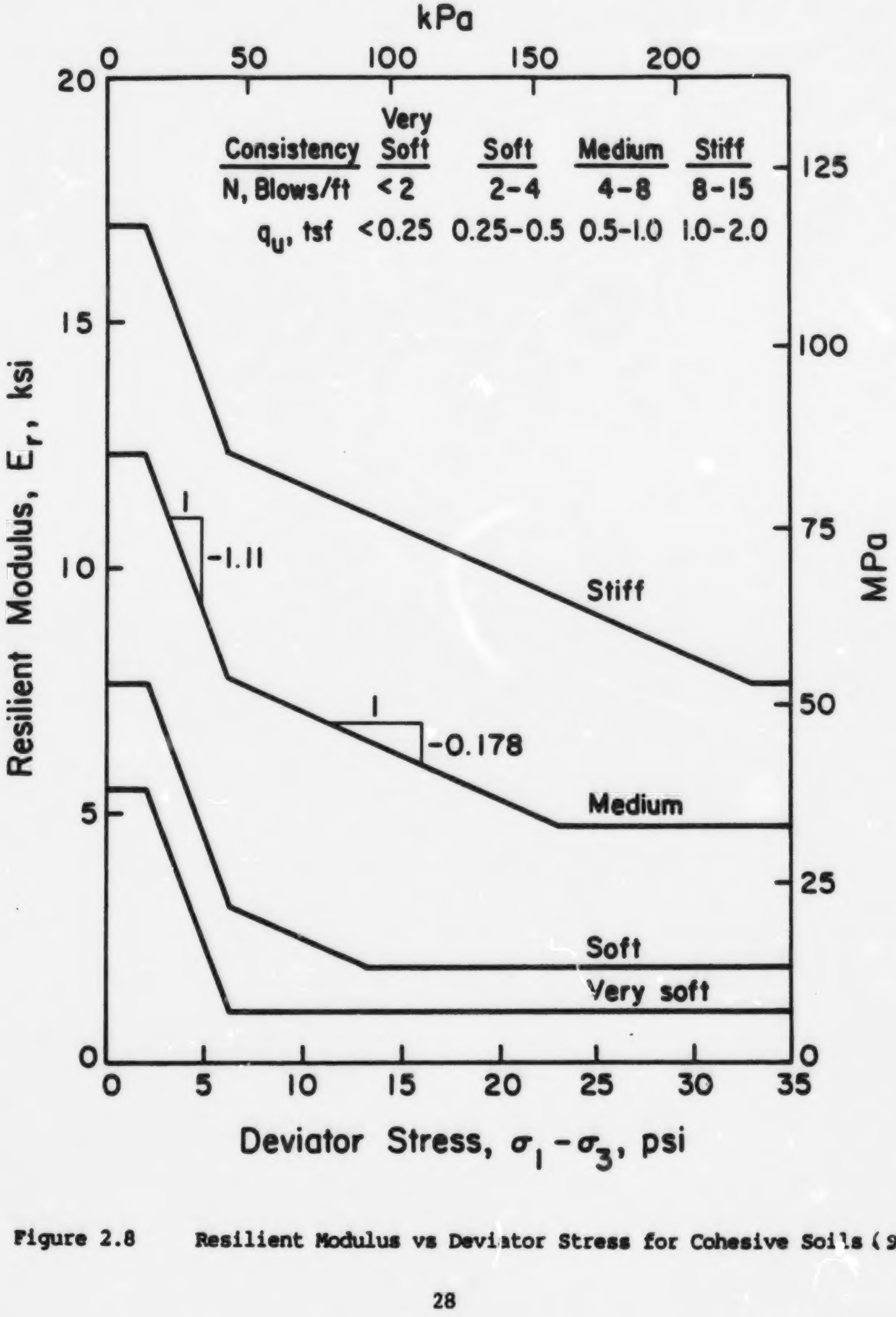


Figure 2.8 Resilient Modulus vs Deviator Stress for Cohesive Soils (9)

vii. **KONE(I)**: Coefficient for calculation of stress-dependent soil modulus.

viii. **KTWO(I)**: Coefficient for calculation of stress-dependent soil modulus.

NOTE: If **KTYPE(I)** = 0 or **KTYPE(I)** ≥ 5, **KONE(I)** and **KTWO(I)** can be input as 0.0.

5. Data Entry Type 5

TIEL	TIESP	TIEWD

KEYBOARD: FREE FORMAT
DATA FILE: FREE FORMAT

i. **TIEL:** Length of tie (in.).

ii. **TIESP:** Center-to-center tie spacing (in.).

iii. **TIEWD:** Tie width at base of tie (in.).

6. Data Entry Type 6

```
---------------------------
 TA     TE     TI      TWT
---------------------------
  KEYBOARD:  FREE FORMAT
 DATA FILE:  FREE FORMAT
```

i. **TA:** Cross-sectional area of tie (in.^{2}).

ii. **TE:** Young's modulus of tie (psi).

iii. **TI:** Moment of inertia of tie about major axis (in.^{4}).

iv. **TWT:** Tie weight (lbs).

NOTE: In the case of varying tie cross-section, e.g., a concrete tie, an average uniform cross-section must be assumed. A combination tie EI may be input by setting either TE or TI equal to unity and inputting the tie EI for the non-unity value.

7. Data Entry Type 7

```
-----------------
     MI     WI
-----------------
 KEYBOARD:  FREE FORMAT
DATA FILE:  FREE FORMAT
```

i. MI: Number of tie segments having centers between the rails. MI = 6 is used for standard U.S. rail spacing.

ii. WI: Rail spacing (in.). Standard rail spacing in U.S. is WI = 59.25 in. between the centers of the rail heads.

8. Data Entry Type 8

```
---------------------------
 RA     RE     RI      RWT
---------------------------
  KEYBOARD:  FREE FORMAT
 DATA FILE:  FREE FORMAT
```

i. **RA:** Rail cross-sectional area (in.^{2}).

ii. **RE:** Young's modulus for rail (psi).

iii. **RI:** Moment of inertia for rail about major axis (in.^{4}).

iv. **RWT:** Rail weight (lbs/yard).

NOTE: A combination rail EI may be input by setting either RE or RI to unity and inputting the rail EI for the non-unity value.

9. Data Entry Type 9

```
------------------
      STIF1
------------------
 KEYBOARD:   FREE FORMAT
DATA FILE:   FREE FORMAT
```

STIF1: Rail fastener or tie pad stiffness. For cut spikes and plates, this stiffness is about 7,000,000 lb/in.

10. Data Entry Type 10

```
------------------
      NAXLES
------------------
 KEYBOARD:   FREE FORMAT
DATA FILE:   FREE FORMAT
```

NAXLES: Number of axles to be applied to the track. NAXLES = 1 for single axle loading. The maximum value is NAXLES = 4.

11. Data Entry Type 11

```
--------------------------
    LP(I)     PWHL(I)
--------------------------
  KEYBOARD:  FREE FORMAT
 DATA FILE:  FREE FORMAT
```

i. **LP(I):** Tie number at which load i is applied. LP(I) must equal 1 for the first entry in this data group.

ii. **PWHL(I):** Wheel load applied to tie i (kips).

NOTE: The number of entries in this data group must be equal to NAXLES. The maximum tie number that can be loaded is tie number 12. PWHL(I) is actually half of the total axle load applied to the rail. since only symmetrical tie loadings are considered, PWHL(I) is the wheel load per axle. Unequal wheel loads can be considered. See Fig. 2.3 for the tie numbering system. If a wheel load needs to be placed at a location midway between the ties, this wheel load may be split into components placed on the adjacent ties, and the number of axle loadings must be increased. See Fig. 2.4 for an example. The maximum number of axle loads is still limited to 4.

12. Data Entry Type 12

```
----------------------------------------
 MINTOUT   MAXTOUT   MINSEG   MAXSEG
----------------------------------------
        KEYBOARD:  FREE FORMAT
       DATA FILE:  FREE FORMAT
```

i. **MINTOUT:** First tie at which output is desired.

ii. **MAXTOUT:** Last tie at which output is desired.

iii. **MINSEG:** First tie segment at which output is desired.

iv. **MAXSEG:** Last tie segment at which output is desired.

NOTE: The possible range for tie output is from tie 1 to tie 17. The assumed loading influence zone is five ties away from any loaded point, i.e., if the last loaded tie is tie number 6, then ties 12 through 17 will be unaffected. Symmetry of rail loading should be considered to reduce output.

The possible range for tie segment output is from segment 1 to segment 5. See Fig. 2.5 for tie segment locations.

13. Data Entry Type 13

```
--------------------------
 ITSTD   ITPRIN   ITRIAX
--------------------------
  KEYBOARD:  FREE FORMAT
 DATA FILE:  FREE FORMAT
```

i. **ITSTD:** Option for printing rail deflections, rail seat loads, tie deflections, tie bending moments, rail bending moments, and the soil stresses beneath the ties.

= 0 Do not print.

= 1 Print.

ii. **ITPRIN:** Option for calculation of principal stresses and direction cosines for the soil stresses beneath the ties.

= 0 Do not calculate.

= 1 Calculate.

iii. **ITRIAX:** Option for calculation of equivalent triaxial states for soil stresses.

= 0 Do not calculate.

= 1 Calculate.

14. Data Entry Type 14

```
---------------------------
ZZ(1), ZZ(2), ... ZZ(NS)
---------------------------
  KEYBOARD:  FREE FORMAT
 DATA FILE:  FREE FORMAT
```

ZZ(I): Depth within layer i that is used to calculate soil modulus. NS values of ZZ(I) must be specified. Do not specify zero as a depth. Do not specify a depth that is located exactly at a layer boundary. Typically, layer mid-depths are used to obtain the average modulus within that layer.

[NOTE: If INTERF = 1, Data Entry Types 15 and 16 must be specified.]

15. Data Entry Type 15

```
-------------------
        NPT
-------------------
 KEYBOARD:  FREE FORMAT
DATA FILE:  FREE FORMAT
```

NPT: Number of additional depth points at which soil stresses are desired. The maximum value is NPT = 5.

16. Data Entry Type 16

```
-------------------
 ZZ(I)     KNOT(I)
-------------------
 KEYBOARD:  FREE FORMAT
DATA FILE:  FREE FORMAT
```

i. ZZ(I): Depth of i^th point at which soil stresses are desired.

ii. KNOT(I): Coefficient of lateral earth pressure at the i^th point.

<u>NOTE</u>: The number of entries in this data group must be equal to NPT. Do not specify zero as a depth point. Do not specify a point exactly at a layer interface. If additional depth points are desired, data groups 15 and 16 must be repeated. Computations will stop after all data have been processed.

[NOTE: Data Entry Type 17 is used only when INTERF = 1 and NOTHER = 1]

17. Data Entry Type 17

```
------
 9999
------
  I4
```

18. Data Entry Type 18

```
-------------
 OFFSET, NPT
-------------
KEYBOARD:   FREE FORMAT
DATA FILE:  FREE FORMAT
```

i. OFFSET: Offset distance from track centerline (in.) at which stresses will be computed. This distance must be larger than one-half the tie length.

ii. NPT: Number of depths corresponding to the offset distance given above, at which stresses will be computed. The maximum value of NPT = 5.

19. Data Entry Type 19

```
---------------------------------
ZZ(1), ZZ(2), ........, ZZ(NPT)
---------------------------------
       KEYBOARD:  FREE FORMAT
      DATA FILE:  FREE FORMAT
```

ZZ(I): Depth of ith point at which soil stresses are desired (in.). NPT values of ZZ(1) must be specified. Do not specify zero as a depth. Do not specify a depth that is located exactly at a layer boundary.

NOTE: If additional offset distances and depths are needed, Data Entry Types 18 and 19 must be repeated. Computations will stop after all data have been processed.

2.4 Typical GEOTRACK Output

The following pages present a typical output file for the GEOTRACK computer program using as an example problem a nominal case documented by Chang, Adegoke and Selig (2). The input data file used to generate the typical output is shown on page 43 . Both the interactively generated file saved from the keyboard input and the equivalent manually created free format data file are illustrated.

EXAMPLE DATA FILES

A) DATA FILE SAVED FROM KEYBOARD INPUT (COMPUTER STYLE FREE FORMAT):

```
EXAMPLE: NOMINAL CASE (ASCE, Vol.108, No.GT11, Nov., 1982)
           2           1           0           0           0           0
           0           0
    45000.0000000  3.000000E-001       12.0000000      104.0000000
        1.0000000            3     1543.0000000      425.0000000
     8000.0000000  4.000000E-001         .0000000      110.0000000
  7.500000E-001            1      877.0000000        1.1000000
      102.0000000       19.5000000        9.0000000
       63.0000000  3.860000E+008        1.0000000      250.0000000
           6       59.2500000
       13.3500000  2.800000E+009        1.0000000      136.0000000
  7000000.0000000
           1
           1       32.9000000
           1           6           1           5
           1           0           1
        6.0000000       15.0000000
```

B) EQUIVALENT INPUT DATA FILE (MANUAL FREE FORMAT CREATION):

```
EXAMPLE: NOMINAL CASE (ASCE, Vol.108, No.GT11, Nov., 1982)
2,1,0,0,0,0
0,0
45000.0,0.3,12.0,104.0,1.0,3,1543.0,425.0
8000.0,0.4,0.0,110.,0.75,1,877.0,1.10
102.0,19.5,9.0
63.0,3.86E8,1.0,250.0
6,59.25
13.35,2.8E9,1.0,136.0
7000000.0
1
1,32.9
1,6,1,5
1,0,1
6.0,15.0
```

Example Output

```
     EXAMPLE: NOMINAL CASE (ASCE, Vol.108, No.GT11, Nov., 1982)

     TIE LENGTH ........................ 102.0  IN.
     NUMBER OF SEGMENTS PER TIE ........ 10
     NUMBER OF SEGMENTS BETWEEN RAILS ..  6
     TIE SPACING ....................... 19.5  IN.
     TIE WIDTH .........................  9.0  IN.
     TIE AREA .......................... 63.0  SQ.IN.
     TIE WEIGHT ........................ 250.0  LBS.
     TIE EI ............................ 386000.0  K-SQ.IN.
     RAIL SPACING ...................... 59.25  IN.
     RAIL AREA ......................... 13.35  SQ.IN.
     RAIL WEIGHT ....................... 136.0  LBS. PER YARD
     RAIL EI ........................... 2800000.0  K-SQ.IN.
     RAIL FASTENER STIFFNESS ........... 7000000.0  LBS. PER IN.
     NUMBER OF AXLE LOADS .............. 1
     AXLE LOADS ARE ON TIE NUMBER(S) ... 1   0   0   0
     WHEEL LOAD PER AXLE (KIPS) ........ 32.90    .00    .00    .00
     NUMBER OF SOIL LAYERS ............. 2
     SOLVE FOR FULL TRACK RESPONSE ..... 1
     NUMBER OF ITERATIONS .............. 0
     CALCULATE AT OTHER DEPTH POINTS ... 0
     CALCULATE AT OFFSET LOCATIONS ..... 0
     LIMIT TIE/BALLAST TENSION ......... 0
     FIRST TIE OUTPUT .................. 1
     LAST TIE OUTPUT ................... 6
     FIRST TIE SEGMENT OUTPUT .......... 1
     LAST TIE SEGMENT OUTPUT ........... 5
     PRINT STANDARD SOIL OUTPUT ........ 1
     PRINT PRINCIPAL STRESSES .......... 0
     PRINT EQUIVALENT TRIAXIAL DATA .... 1


LAYER        MODULUS      VRAT       DEPTH      GAMMA     KNOT
              (PSI)                  (IN.)      (PCF)

  1          45000.        .30       12.00      104.0     1.00
  2           8000.        .40         .00      110.0      .75


LAYER    KTYPE              MODULUS DESCRIPTION

  1        3     E - BULK STRESS          K1 =  1543.00  K2 =  425.000
  2        1     LOG E - LOG BULK STRESS  K1 =   877.00  K2 =    1.100
```

```
          DIFFERENT DEPTHS AT WHICH MODULI ARE COMPUTED

                         Z(1) =   6.00 IN.

                         Z(2) =  15.00 IN.


                   CALC. STEP NO. 1
          ---------------------------------------
              DEFLECTIONS AND REACTIONS
              NEGATIVE DEFLECTION IS DOWNWARD
              NEGATIVE REACTION IS TENSION
          ---------------------------------------


                 ---- SINGLE AXLE ----


   TIE      DEFLECTION        REACTION       DEFLECTION
   NO.         RAIL           RAIL SEAT          TIE
                IN.              LBS              IN.

    1       -.085854          11753.9          -.084175
    2       -.074245           7352.5          -.073195
    3       -.054840           3114.5          -.054395
    4       -.038038            944.0          -.037903
    5       -.025078            -67.7          -.025088
    6       -.014188           -770.2          -.014298


   TIE        TIE CENTER         TIE RAIL-SEAT
   NO.      BENDING MOMENT      BENDING MOMENT
              (IN.-LBS)            (IN.-LBS)

    1        -.13947E+05          .54286E+05
    2        -.80441E+04          .35722E+05
    3        -.23023E+04          .16398E+05
    4         .25178E+03          .57465E+04
    5         .11331E+04          .46829E+03
    6         .16054E+04         -.29049E+04


   TIE               TIE/SOIL REACTIONS, LBS
   NO.       DIV 1        DIV 2        DIV 3        DIV 4        DIV 5

    1       2152.4       3169.8       3438.5       1897.8       1095.3
    2       1494.7       1875.8       2052.6       1178.3        751.1
    3        733.9        733.2        819.2        489.4        338.8
    4        281.2        192.6        225.7        140.4        104.1
    5         45.7        -45.3        -39.5        -19.6         -9.0
    6        -90.7       -235.3       -247.8       -130.4        -66.1
    TIE             TIE SEGMENT DEFLECTION ,IN.
    NO.        DIV 1         DIV 2         DIV 3         DIV 4         DIV 5

      1     -.068091      -.079888      -.084671      -.081536      -.078279
      2     -.061043      -.069831      -.073874      -.072486      -.070662
      3     -.047332      -.052323      -.055055      -.055125      -.054660
      4     -.034403      -.036808      -.038380      -.038913      -.039029
      5     -.023747      -.024617      -.025380      -.025953      -.026254
      6     -.014281      -.014213      -.014479      -.015072      -.015475

    PEAK RAIL BENDING MOMENT=    .23969E+06 IN.-LBS

    TRACK MODULUS U =    4.937 KIPS/IN./IN.  =     34.036 MN/M/M


          SOIL VERTICAL DISPLACEMENTS AND INCREMENTAL STRESSES

                   T=TIE NUMBER (1=CENTER TIE)
                   SEG=SEGMENT NUMBER
                   Z=DEPTH POINT NUMBER

                   UNITS ARE INCHES AND PSI.
                   COMPRESSION IS NEGATIVE FOR STRESSES
                   DOWNWARD IS POSITIVE FOR DEFLECTIONS


                   Z(1) =    6.00 IN.

                   Z(2) =   15.00 IN.


T  SEG  Z        W      THETA    S-XX     S-YY    S-ZZ     S-XY     S-XZ     S-YZ
-------------------------------------------------------------------------------------


1   1   1   .06649   -24.0    -5.4     -3.6   -15.1       .0     -6.0       .0
1   1   2   .06298   -12.2    -2.8     -2.2    -7.1       .0     -2.5       .0


1   2   1   .07753   -34.1    -7.5     -4.3   -22.2       .0     -2.6       .0
1   2   2   .07224   -15.6    -3.0     -2.8    -9.8       .0     -1.4       .0


1   3   1   .08205   -35.9    -7.7     -4.7   -23.6       .0      2.2       .0
1   3   2   .07659   -16.7    -3.4     -3.0   -10.3       .0       .1       .0


1   4   1   .08021   -26.3    -7.3     -4.3   -14.7       .0      4.2       .0
1   4   2   .07644   -15.6    -4.1     -2.8    -8.7       .0       .9       .0


1   5   1   .07756   -19.6    -6.3     -4.0    -9.4       .0      1.7       .0
1   5   2   .07506   -14.3    -4.5     -2.6    -7.2       .0       .4       .0
```

```
T  SEG  Z      W      THETA   S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
---------------------------------------------------------------------------


2   1   1   .05993  -17.6   -4.0    -3.2   -10.5     -.1    -3.9     1.2
2   1   2   .05754   -9.9   -2.3    -2.2    -5.4      .5    -1.9     1.1


2   2   1   .06850  -23.1   -5.5    -3.8   -13.7     -.1    -1.4     1.8
2   2   2   .06510  -12.5   -2.4    -2.8    -7.2      .3    -1.0     1.4


2   3   1   .07236  -24.3   -5.6    -4.1   -14.6     -.2     1.4     1.8
2   3   2   .06889  -13.3   -2.8    -3.0    -7.5      .0      .0     1.5


2   4   1   .07169  -18.7   -5.4    -3.7    -9.5     -.2     2.6     1.4
2   4   2   .06925  -12.6   -3.3    -2.8    -6.5     -.1      .6     1.4


2   5   1   .07016  -14.9   -4.8    -3.5    -6.6     -.1     1.1     1.0
2   5   2   .06849  -11.8   -3.6    -2.6    -5.5     -.1      .3     1.2

T  SEG  Z      W      THETA   S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
---------------------------------------------------------------------------


3   1   1   .04677   -9.4   -2.3    -2.0    -5.1     -.2    -1.6      .9
3   1   2   .04576   -5.9   -1.3    -1.8    -2.8      .5    -1.0     1.1


3   2   1   .05182  -11.1   -3.1    -2.3    -5.7     -.2     -.4     1.3
3   2   2   .05049   -7.2   -1.5    -2.2    -3.6      .3     -.5     1.4


3   3   1   .05446  -11.7   -3.1    -2.4    -6.1     -.2      .6     1.3
3   3   2   .05313   -7.7   -1.6    -2.3    -3.7      .1      .0     1.5


3   4   1   .05479   -9.5   -3.1    -2.3    -4.1     -.2     1.1     1.0
3   4   2   .05389   -7.5   -1.9    -2.2    -3.3      .0      .2     1.4


3   5   1   .05442   -8.1   -2.9    -2.1    -3.1     -.1      .4      .8
3   5   2   .05383   -7.1   -2.1    -2.1    -2.9      .0      .1     1.3
```

```
T  SEG  Z       W      THETA   S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
-----------------------------------------------------------------------------


4   1   1   .03418    -4.0    -1.2     -.9    -1.9     -.3     -.4      .4
4   1   2   .03394    -2.8     -.6    -1.1    -1.1      .4     -.4      .7


4   2   1   .03669    -4.2    -1.6    -1.0    -1.6     -.2      .0      .6
4   2   2   .03643    -3.3     -.7    -1.3    -1.3      .2     -.2      .9


4   3   1   .03823    -4.4    -1.6    -1.0    -1.7     -.2      .2      .6
4   3   2   .03800    -3.4     -.8    -1.4    -1.3      .1      .0     1.0


4   4   1   .03883    -3.8    -1.6    -1.0    -1.2     -.1      .3      .4
4   4   2   .03872    -3.4     -.9    -1.4    -1.2      .0      .1     1.0


4   5   1   .03896    -3.4    -1.6     -.9    -1.0     -.1      .1      .3
4   5   2   .03895    -3.3     -.9    -1.3    -1.0      .0      .0      .9

T  SEG  Z       W      THETA   S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
-----------------------------------------------------------------------------


5   1   1   .02371    -1.1     -.5     -.3     -.3     -.2      .1      .2
5   1   2   .02381     -.9     -.2     -.6     -.1      .2     -.1      .4


5   2   1   .02466     -.6     -.7     -.2      .2     -.2      .2      .3
5   2   2   .02486     -.9     -.2     -.6     -.1      .1      .0      .5


5   3   1   .02542     -.6     -.7     -.2      .2     -.2      .0      .3
5   3   2   .02565    -1.0     -.2     -.7      .0      .1      .0      .6


5   4   1   .02598     -.8     -.7     -.2      .1     -.1      .0      .2
5   4   2   .02620    -1.0     -.2     -.7     -.1      .0      .0      .5


5   5   1   .02627     -.9     -.7     -.2      .1      .0      .0      .1
5   5   2   .02648    -1.0     -.2     -.7     -.1      .0      .0      .5
```

T	SEG	Z	W	THETA	S-XX	S-YY	S-ZZ	S-XY	S-XZ	S-YZ
6	1	1	.01434	.5	-.1	.0	.6	-.2	.4	.0
6	1	2	.01460	.0	.0	-.3	.3	.1	.1	.1
6	2	1	.01440	1.5	-.1	.0	1.5	-.1	.3	-.1
6	2	2	.01483	.2	.0	-.3	.5	.0	.1	.1
6	3	1	.01468	1.6	-.1	.1	1.6	-.1	-.1	-.1
6	3	2	.01514	.2	.0	-.3	.5	.0	.0	.1
6	4	1	.01518	.9	-.1	.1	1.0	-.1	-.3	-.1
6	4	2	.01553	.1	.0	-.3	.4	.0	-.1	.2
6	5	1	.01553	.4	-.2	.1	.5	.0	-.1	-.1
6	5	2	.01579	.0	.1	-.3	.3	.0	.0	.2

```
                                GEOSTAT.  INIT.  INIT.                    EQUIVALENT TRIAXIAL STATES
TIE SEG POINT DEPTH KNOT VERT.STR.  P      Q      SOCT   TOCT  SIG 1  SIG 3  MAX P  MAX Q
               (IN.)        (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)
------------------------------------------------------------------------------------------

 1   1    1    6.0  1.00     .72    .72    .00   8.72   7.02  18.65   3.75  11.20   7.45
 1   1    2   15.0   .75    1.27   1.11    .16   5.11   3.06   9.43   2.95   6.19   3.24

------------------------------------------------------------------------------------------

 1   2    1    6.0  1.00     .85    .85    .00  12.21   8.04  23.58   6.52  15.05   8.53
 1   2    2   15.0   .75    1.40   1.22    .17   6.37   3.56  11.40   3.86   7.63   3.77

------------------------------------------------------------------------------------------

 1   3    1    6.0  1.00     .94    .94    .00  12.92   8.52  24.98   6.89  15.94   9.04
 1   3    2   15.0   .75    1.49   1.31    .19   6.80   3.46  11.70   4.35   8.02   3.67

------------------------------------------------------------------------------------------

 1   4    1    6.0  1.00     .74    .74    .00   9.50   5.54  17.33   5.58  11.45   5.87
 1   4    2   15.0   .75    1.29   1.13    .16   6.27   2.71  10.10   4.35   7.22   2.87

------------------------------------------------------------------------------------------

 1   5    1    6.0  1.00     .72    .72    .00   7.27   2.58  10.92   5.44   8.18   2.74
 1   5    2   15.0   .75    1.27   1.11    .16   5.82   2.00   8.64   4.40   6.52   2.12


                                GEOSTAT.  INIT.  INIT.                    EQUIVALENT TRIAXIAL STATES
TIE SEG POINT DEPTH KNOT VERT.STR.  P      Q      SOCT   TOCT  SIG 1  SIG 3  MAX P  MAX Q
               (IN.)        (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)
------------------------------------------------------------------------------------------

 2   1    1    6.0  1.00     .72    .72    .00   6.60   4.62  13.13   3.33   8.23   4.90
 2   1    2   15.0   .75    1.27   1.11    .16   4.36   2.31   7.62   2.72   5.17   2.45

------------------------------------------------------------------------------------------

 2   2    1    6.0  1.00     .85    .85    .00   8.54   4.69  15.18   5.23  10.20   4.97
 2   2    2   15.0   .75    1.40   1.22    .17   5.33   2.71   9.16   3.41   6.28   2.87

------------------------------------------------------------------------------------------

 2   3    1    6.0  1.00     .94    .94    .00   9.05   5.03  16.16   5.49  10.82   5.34
 2   3    2   15.0   .75    1.49   1.31    .19   5.68   2.58   9.34   3.86   6.60   2.74

------------------------------------------------------------------------------------------

 2   4    1    6.0  1.00     .74    .74    .00   6.98   3.37  11.74   4.60   8.17   3.57
 2   4    2   15.0   .75    1.29   1.13    .16   5.29   2.00   8.12   3.87   5.99   2.12

------------------------------------------------------------------------------------------

 2   5    1    6.0  1.00     .72    .72    .00   5.69   1.63   8.00   4.54   6.27   1.73
 2   5    2   15.0   .75    1.27   1.11    .16   4.98   1.63   7.29   3.82   5.55   1.73
```

```
                             GEOSTAT.  INIT.  INIT.                   EQUIVALENT TRIAXIAL STATES
TIE SEG POINT DEPTH KNOT VERT.STR.  P      Q      SOCT   TOCT   SIG 1  SIG 3  MAX P  MAX Q
              (IN.)       (PSI)   (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)
--------------------------------------------------------------------------------------------

 3   1   1    6.0  1.00    .72     .72    .00   3.85   2.00   6.68   2.44   4.56   2.12
 3   1   2   15.0   .75   1.27    1.11    .16   3.03   1.41   5.03   2.03   3.53   1.50

--------------------------------------------------------------------------------------------

 3   2   1    6.0  1.00    .85     .85    .00   4.55   1.83   7.13   3.26   5.19   1.94
 3   2   2   15.0   .75   1.40    1.22    .17   3.58   1.63   5.89   2.43   4.16   1.73

--------------------------------------------------------------------------------------------

 3   3   1    6.0  1.00    .94     .94    .00   4.83   1.83   7.41   3.54   5.48   1.94
 3   3   2   15.0   .75   1.49    1.31    .19   3.82   1.41   5.82   2.82   4.32   1.50

--------------------------------------------------------------------------------------------

 3   4   1    6.0  1.00    .74     .74    .00   3.92   1.41   5.92   2.92   4.42   1.50
 3   4   2   15.0   .75   1.29    1.13    .16   3.57   1.15   5.20   2.75   3.97   1.22

--------------------------------------------------------------------------------------------

 3   5   1    6.0  1.00    .72     .72    .00   3.42    .82   4.57   2.84   3.71    .87
 3   5   2   15.0   .75   1.27    1.11    .16   3.42   1.15   5.05   2.60   3.83   1.22


                             GEOSTAT.  INIT.  INIT.                   EQUIVALENT TRIAXIAL STATES
TIE SEG POINT DEPTH KNOT VERT.STR.  P      Q      SOCT   TOCT   SIG 1  SIG 3  MAX P  MAX Q
              (IN.)       (PSI)   (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)
--------------------------------------------------------------------------------------------

 4   1   1    6.0  1.00    .72     .72    .00   2.06    .00   2.06   2.06   2.06    .00
 4   1   2   15.0   .75   1.27    1.11    .16   1.98    .00   1.98   1.98   1.98    .00

--------------------------------------------------------------------------------------------

 4   2   1    6.0  1.00    .85     .85    .00   2.24    .00   2.24   2.24   2.24    .00
 4   2   2   15.0   .75   1.40    1.22    .17   2.25    .82   3.41   1.67   2.54    .87

--------------------------------------------------------------------------------------------

 4   3   1    6.0  1.00    .94     .94    .00   2.39    .00   2.39   2.39   2.39    .00
 4   3   2   15.0   .75   1.49    1.31    .19   2.39    .82   3.55   1.82   2.68    .87

--------------------------------------------------------------------------------------------

 4   4   1    6.0  1.00    .74     .74    .00   2.01    .00   2.01   2.01   2.01    .00
 4   4   2   15.0   .75   1.29    1.13    .16   2.21    .82   3.37   1.63   2.50    .87

--------------------------------------------------------------------------------------------

 4   5   1    6.0  1.00    .72     .72    .00   1.86    .00   1.86   1.86   1.86    .00
 4   5   2   15.0   .75   1.27    1.11    .16   2.15    .00   2.15   2.15   2.15    .00
```

```
                            GEOSTAT.  INIT.  INIT.                 EQUIVALENT TRIAXIAL STATES
TIE SEG POINT DEPTH KNOT VERT.STR.  P      Q      SOCT   TOCT  SIG 1  SIG 3  MAX P  MAX Q
              (IN.)         (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)
------------------------------------------------------------------------------------------

 5   1    1    6.0  1.00     .72    .72    .00   1.08    .00   1.08   1.08   1.08    .00
 5   1    2   15.0   .75    1.27   1.11    .16   1.35    .00   1.35   1.35   1.35    .00

------------------------------------------------------------------------------------------

 5   2    1    6.0  1.00     .85    .85    .00   1.06    .00   1.06   1.06   1.06    .00
 5   2    2   15.0   .75    1.40   1.22    .17   1.47    .00   1.47   1.47   1.47    .00

------------------------------------------------------------------------------------------

 5   3    1    6.0  1.00     .94    .94    .00   1.16    .00   1.16   1.16   1.16    .00
 5   3    2   15.0   .75    1.49   1.31    .19   1.56    .00   1.56   1.56   1.56    .00

------------------------------------------------------------------------------------------

 5   4    1    6.0  1.00     .74    .74    .00   1.00    .00   1.00   1.00   1.00    .00
 5   4    2   15.0   .75    1.29   1.13    .16   1.41    .00   1.41   1.41   1.41    .00

------------------------------------------------------------------------------------------

 5   5    1    6.0  1.00     .72    .72    .00   1.00    .00   1.00   1.00   1.00    .00
 5   5    2   15.0   .75    1.27   1.11    .16   1.39    .00   1.39   1.39   1.39    .00


                            GEOSTAT.  INIT.  INIT.                 EQUIVALENT TRIAXIAL STATES
TIE SEG POINT DEPTH KNOT VERT.STR.  P      Q      SOCT   TOCT  SIG 1  SIG 3  MAX P  MAX Q
              (IN.)         (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)  (PSI)
------------------------------------------------------------------------------------------

 6   1    1    6.0  1.00     .72    .72    .00    .54    .00    .54    .54    .54    .00
 6   1    2   15.0   .75    1.27   1.11    .16   1.05    .00   1.05   1.05   1.05    .00

------------------------------------------------------------------------------------------

 6   2    1    6.0  1.00     .85    .85    .00    .34    .00    .34    .34    .34    .00
 6   2    2   15.0   .75    1.40   1.22    .17   1.11    .00   1.11   1.11   1.11    .00

------------------------------------------------------------------------------------------

 6   3    1    6.0  1.00     .94    .94    .00    .40    .00    .40    .40    .40    .00
 6   3    2   15.0   .75    1.49   1.31    .19   1.17    .00   1.17   1.17   1.17    .00

------------------------------------------------------------------------------------------

 6   4    1    6.0  1.00     .74    .74    .00    .44    .00    .44    .44    .44    .00
 6   4    2   15.0   .75    1.29   1.13    .16   1.04    .00   1.04   1.04   1.04    .00

------------------------------------------------------------------------------------------

 6   5    1    6.0  1.00     .72    .72    .00    .58    .00    .58    .58    .58    .00
 6   5    2   15.0   .75    1.27   1.11    .16   1.04    .00   1.04   1.04   1.04    .00
```

2.5 Use of the GEOTRACK Computer Program for the Stress Analysis Side of a Bearing Capacity Design Approach

The comments in this section apply to the use of the GEOTRACK computer program for the purpose of modelling the stress distributions in the subgrade of a tie-track system. This section is of value to the user who desires to use the GEOTRACK computer program to develop further bearing capacity design charts or do specific designs according to the methods described in the final report (1).

An example input and output file which was created for the development of the stress charts, presented in Section 5.2 of the body of the report (i.e., "The Development of Bearing Capacity Design Charts for Track Systems" (1)), is presented on pages through . The GEOTRACK computer program requires the input of British Imperial units and the input and output file values are therefore in Imperial units. The input file was named E103T36.DAT, while the corresponding output file was named E1035T36.OGT with the characteristic '.OGT' suffix required for the purpose of using the GEOPLOT and the STRESS post-processing computer programs on the GEOTRACK output file.

The incremental vertical stress at the ballast surface and the incremental vertical stress at the subgrade surface are important to the bearing capacity design approach developed in this project. The GEOTRACK model was used to predict the vertical stresses at each of the ballast and subgrade surfaces. These stresses were obtained by requesting the standard soil output, i.e., for Data Entry Type 13, setting ITSTD = 1. The variables ITPRIN and ITRIAX were set to zero to facilitate quicker computational time.

Four wheel loads corresponding to double truck loading for a

263,000 lb car (i.e., dynamic axle loads equal to 1.5 times the actual wheel loads) were applied at ties 1, 4, 8, and 11. The loads were applied at these ties to most closely correspond to the actual distances between the axle loads, realizing that the GEOTRACK computer program will only accept a maximum of four axle loads and that these loads must be placed directly over a tie (See Data Entry Type 11). Equivalent axle loads (i.e., as described in Figure 2.4) could have been used if fewer one axle loads were desired. However, the requirement to model double truck loading (i.e., four axle loads) restrained the use of equivalent axle loads placed to exactly simulate the actual loading configuration. The differences in loading placement is assumed to be negligible.

The maximum 5 soil layers were used to enhance accuracy of the computations. Two additional depth points were entered through Data Entry Type 15 and Data Entry Type 16. The use of additional depth points allowed the computation of an average soil modulus at the layer mid-depth as recommended in Data Entry Type 14. Two additional depths, corresponding to 25 mm below the ballast surface and 25 mm below the subgrade surface were used to compute the ballast surface stress distribution and the subgrade surfaces stress distribution. An actual surface depth for the subgrade cannot be used because the surface of the subgrade occurs at an interface between different soil layers. The same is also true for the ballast surface.

For the purposes of the bearing capacity design approach developed in the final report (1), the GEOTRACK program was used without allowing the soil moduli to converge within the soil layers, i.e., Data Entry Type 2 variable NITER was set to zero. Reasonable moduli values based on current literature were chosen to represent the respective soil layers. If the moduli had been allowed to converge, the design charts presented in the final report (1) could not have been developed for specific moduli values. If alternate design charts could have been developed, their use would have been severely limited.

Consequently, the design charts presented in the final report (1) may be used for the normal working range of soil moduli. Track systems placed upon weak soils, which exhibit low repeated loading moduli, should be designed using the GEOTRACK computer program for a complete stress analysis with moduli convergence.

Although the GEOTRACK program provides the option of limiting the tie-ballast reactions, this option was not used, i.e., the variable NOTENS in Data Entry Type 2 was set to zero. Since the stresses most significant to the bearing capacity approach are the stresses immediately beneath the loaded area, their was little need for limiting the tie-ballast reactions.

The output file from the GEOTRACK computer program, presented in pages to , summarizes the data input and presents standard data on tie and rail deflections, tie and rail bending moments, rail seat reactions and tie-soil reactions. The stress distributions for each of the desired tie segments and tie numbers follows. For the particular case shown, only the incremental vertical, horizontal and shear stress data was required. (The user could also have requested stress distributions for the principal stresses and the equivalent triaxial stresses, however, these stresses were not used for the bearing capacity approach and therefore were not requested. This minimized the file size and run time for the GEOTRACK computer program.) The results for the incremental stresses are then presented for the additional depths. The output file is 21 pages long. The need for the post-processing graphics package, GEOPLOT, and the post-processing stress averaging program, STRESS, becomes apparent in view of the lengthy GEOTRACK output files required.

```
FILE NAME E1035T36
           5           1           0           1           0           0
           0           0
    35000.000000    3.000000E-01       12.000000      125.000000
        1.000000           1        1058.00000       0.593000
    35000.000000    3.000000E-01       12.000000      125.000000
        1.000000           1         941.00000       0.687000
    35000.000000    3.000000E-01       12.000000      125.000000
        1.000000           1         941.00000       0.687000
    10000.000000    4.000000E-01    36.000000E+00     125.000000
    7.5000000E-01           1       877.0             1.10
    10000.000000    4.000000E-01    0.0000000E+00     125.000000
    7.5000000E-01           1       877.0             1.10
      102.000000       20.0000000        9.000000
       63.000000   2.4000E+06       257.3        250.000000
           6      59.250000
       13.350000    3.000000E+07       94.90000      115.000000
  7000000.000000
           4
           1      49.400000
           4      49.4
           8      49.4
          11      49.4
           1          16           1           5
           1           0           0
        6.000000   18.00000    30.000000    54.00000   120.00000
        2
        1.000000  1.0
        37.00000  7.5000E-01
```

COMPONENT PARTS OF FILE E1035T36

COMMENT LINE

```
FILE NAME E1035T36
```

NO. OF SOIL LAYERS
SOLVE ENTIRE PROBLEM
ADDITIONAL DEPTHS REQUIRED
COMPUTATIONS BENEATH TRACK STRUCTURE ONLY

```
   5          1          0          1          0          0
   0          0
```

DO NOT PRINT INFLUENCE COEFFICIENTS
PRINT ONLY RESULTS FROM FINAL ITERATION
ZERO ITERATIONS
DO NOT LIMIT TIE-SOIL TENSIONS

E
K_o
μ
LAYER THICKNESS
γ

```
35000.000000    3.000000E-01      12.000000      125.000000
    1.000000       1           1058.00000          0.593000
35000.000000    3.000000E-01      12.000000      125.000000
    1.000000       1            941.00000          0.687000
35000.000000    3.000000E-01      12.000000      125.000000
    1.000000       1            941.00000          0.687000
10000.000000    4.000000E-01   36.000000E+00     125.000000
7.5000000E-01      1            877.0              1.10
10000.000000    4.000000E-01    0.0000000E+00    125.000000
7.5000000E-01      1            877.0              1.10
```

STRESS DEPENDENT EQUATION TYPE
STRESS DEPENDENT EQUATION CONSTANTS

TIE LENGTH
TIE SPACING
TIE WIDTH

```
102.000000     20.0000000            9.000000
 63.000000     2.4000E+06      257.3           250.000000
```

TIE CROSS-SECTIONAL AREA
TIE MODULUS
TIE MOMENT OF INERTIA
TIE WEIGHT

NO. OF TIE SEGMENTS HAVING CENTERS BETWEEN RAILS
RAIL SPACING
RAIL WEIGHT

```
       6        59.250000
13.350000       3.000000E+07     94.90000     115.000000
7000000.000000
```

RAIL CROSS-SECTIONAL AREA
RAIL MODULUS
RAIL MOMENT OF INERTIA
FASTENER STIFFNESS

NO. OF AXLES
APPLIED LOAD
TIE NO. AT WHICH LOAD APPLIED

```
   4
   1        49.400000
   4        49.4
   8        49.4
  11        49.4
```

FIRST TIE SEGMENT AT WHICH OUTPUT DESIRED
LAST TIE SEGMENT AT WHICH OUTPUT DESIRED

```
   1        16        1         5
   1         0        0
```

FIRST TIE AT WHICH OUTPUT DESIRED
LAST TIE AT WHICH OUTPUT DESIRED
PRINT STANDARD SOIL DATA AND INCREMENTAL STRESSES
DO NOT PRINT PRINCIPAL STRESSES
DO NOT PRINT EQUIVALENT TRIAXIAL STATES

```
6.000000   18.00000   30.000000   54.00000   120.00000
```

DEPTH WITHIN LAYER USED TO CALCULATE SOIL MODULUS

NUMBER OF ADDITIONAL DEPTH POINTS

```
2
1.000000   1.0
37.00000   7.5000E-01
```

K_o OF ADDITIONAL POINT
DEPTH OF ADDITIONAL POINT

```
FILE NAME E1035T36


TIE LENGTH ......................... 102.0  IN.
NUMBER OF SEGMENTS PER TIE ........ 10
NUMBER OF SEGMENTS BETWEEN RAILS ..  6
TIE SPACING ....................... 20.0  IN.
TIE WIDTH .........................  9.0  IN.
TIE AREA .......................... 63.0  SQ.IN.
TIE WEIGHT ........................ 250.0  LBS
TIE EI ...........................   .61752E+09  LB-SQ.IN.
RAIL SPACING ...................... 59.25  IN.
RAIL AREA ......................... 13.35  SQ.IN.
RAIL WEIGHT ....................... 115.0  LBS PER YARD
RAIL EI ..........................   .28470E+10  LB-SQ.IN.
RAIL FASTENER STIFFNESS ........... 7000000.0  LBS PER IN.
NUMBER OF AXLE LOADS .............. 4
AXLE LOADS ARE ON TIE NUMBER(S) ... 1   4   8  11
WHEEL LOAD PER AXLE (KIPS) ........ 49.40  49.40  49.40  49.40
NUMBER OF SOIL LAYERS ............. 5
SOLVE FOR FULL TRACK RESPONSE ..... 1
NUMBER OF ITERATIONS .............. 0
CALCULATE AT OTHER DEPTH POINTS ... 1
CALCULATE AT OFFSET LOCATIONS ..... 0
LIMIT TIE/BALLAST TENSION ......... 0
FIRST TIE OUTPUT .................. 1
LAST TIE OUTPUT ...................16
FIRST TIE SEGMENT OUTPUT .......... 1
LAST TIE SEGMENT OUTPUT ........... 5
PRINT STANDARD SOIL OUTPUT ........ 1
PRINT PRINCIPAL STRESSES .......... 0
PRINT EQUIVALENT TRIAXIAL DATA .... 0


LAYER         MODULUS       VRAT        DEPTH       GAMMA      KNOT
               (PSI)                    (IN.)       (PCF)

  1           35000.        .30         12.00       125.0      1.00
  2           35000.        .30         12.00       125.0      1.00
  3           35000.        .30         12.00       125.0      1.00
  4           10000.        .40         36.00       125.0       .75
  5           10000.        .40           .00       125.0       .75

LAYER     KTYPE                  MODULUS DESCRIPTION

  1         1      LOG E - LOG BULK STRESS K1 =  1058.00  K2 =      .593
  2         1      LOG E - LOG BULK STRESS K1 =   941.00  K2 =      .687
  3         1      LOG E - LOG BULK STRESS K1 =   941.00  K2 =      .687
  4         1      LOG E - LOG BULK STRESS K1 =   877.00  K2 =     1.100
  5         1      LOG E - LOG BULK STRESS K1 =   877.00  K2 =     1.100

            DIFFERENT DEPTHS AT WHICH MODULI ARE COMPUTED

                      Z(1) =   6.00 IN.

                      Z(2) =  18.00 IN.

                      Z(3) =  30.00 IN.

                      Z(4) =  54.00 IN.
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                        Z(5) = 120.00 IN.


                  CALC. STEP NO. 1
           ----------------------------------------
               DEFLECTIONS AND REACTIONS
               NEGATIVE DEFLECTION IS DOWNWARD
               NEGATIVE REACTION IS TENSION
           ----------------------------------------

                 ---- SINGLE AXLE ----

TIE      DEFLECTION       REACTION      DEFLECTION
NO.         RAIL          RAIL SEAT         TIE
            IN.              LBS            IN.

  1      -.091500         20322.3        -.088597
  2      -.077567         12016.3        -.075851
  3      -.057378          3496.4        -.056879
  4      -.042010           127.9        -.041992
  5      -.030305          -878.6        -.030430
  6      -.019638          -223.1        -.019670

TIE        TIE CENTER       TIE RAIL-SEAT
NO.      BENDING MOMENT     BENDING MOMENT
           (IN.-LBS)          (IN.-LBS)

  1        -.27194E+05        .93806E+05
  2        -.14061E+05        .57351E+05
  3        -.11103E+04        .18857E+05
  4         .30761E+04        .27086E+04
  5         .34688E+04       -.26339E+04
  6         .14125E+04       -.42089E+03

TIE              TIE/SOIL REACTIONS, LBS
NO.        DIV 1        DIV 2        DIV 3        DIV 4        DIV 5

  1       3710.2       5501.7       5699.7       3451.8       1958.9
  2       2331.4       3194.6       3294.3       2015.5       1180.5
  3        829.5        881.8        891.1        552.4        341.6
  4        167.1         -1.9        -19.9        -14.0         -3.4
  5        -65.2       -258.9       -280.4       -174.1       -100.0
  6         -1.4        -65.6        -73.1        -49.5        -33.6

TIE              TIE SEGMENT DEFLECTION ,IN.
NO.        DIV 1        DIV 2        DIV 3        DIV 4        DIV 5

  1     -.072715     -.084520     -.088758     -.084511     -.080490
  2     -.064499     -.072767     -.076341     -.074547     -.072516
  3     -.051038     -.055099     -.057548     -.058017     -.057928
  4     -.039272     -.041050     -.042545     -.043570     -.044088
  5     -.029310     -.029974     -.030806     -.031725     -.032281
  6     -.019014     -.019422     -.019847     -.020241     -.020470

PEAK RAIL BENDING MOMENT=   .29526E+06 IN.-LBS

TRACK MODULUS U =   7.754 KIPS/IN./IN.  =    53.459 MN/M/M

          SUPERIMPOSED RESULTS FROM CALC. STEP NO.  1
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                ----- DEFLECTIONS AND REACTIONS ----

TIE       DEFLECTION        REACTION        DEFLECTION
NO.          RAIL           RAIL SEAT          TIE
             IN.              LBS              IN.

  1       -.133510          20450.2         -.130589
  2       -.134945          15512.7         -.132729
  3       -.154584          15289.5         -.152400
  4       -.163815          19571.6         -.161019
  5       -.149882          11265.6         -.148273
  6       -.154032           6546.5         -.153097
  7       -.149882          11265.6         -.148273
  8       -.163815          19571.6         -.161019
  9       -.154584          15289.5         -.152400
 10       -.134945          15512.7         -.132729
 11       -.133510          20450.2         -.130589
 12       -.107872          11137.7         -.106281
 13       -.077016           3273.3         -.076549
 14       -.042010            127.9         -.041992
 15       -.030305           -878.6         -.030430
 16       -.019638           -223.1         -.019670

          TIE CENTER     TIE RAIL-SEAT        RAIL
TIE        BENDING          BENDING          BENDING
NO.        MOMENT           MOMENT           MOMENT
         (IN.-LBS)        (IN.-LBS)        (IN.-LBS)

  1      -.24118E+05      .96515E+05       .26876E+06
  2      -.15172E+05      .76208E+05      -.41493E+05
  3      -.13759E+05      .75787E+05      -.41492E+05
  4      -.20650E+05      .93881E+05       .26430E+06
  5      -.75166E+04      .57426E+05      -.26480E+05
  6       .60437E+03      .36872E+05      -.91945E+05
  7      -.75166E+04      .57426E+05      -.26479E+05
  8      -.20650E+05      .93881E+05       .26430E+06
  9      -.13759E+05      .75787E+05      -.41493E+05
 10      -.15172E+05      .76208E+05      -.41493E+05
 11      -.24118E+05      .96515E+05       .26876E+06
 12      -.10593E+05      .54717E+05       .16780E+02
 13       .30218E+03      .18436E+05      -.45972E+05
 14       .30761E+04      .27086E+04      -.26496E+05
 15       .34688E+04     -.26339E+04      -.44625E+04
 16       .14125E+04     -.42089E+03       .00000E+00

TIE                 TIE/SOIL REACTIONS, LBS
NO.       DIV 1          DIV 2          DIV 3          DIV 4          DIV 5

  1       3877.3         5499.9         5679.8         3437.8         1955.5
  2       3161.0         4076.3         4185.3         2567.9         1522.1
  3       3159.6         4010.7         4112.2         2518.5         1488.5
  4       3812.1         5240.9         5399.4         3263.7         1855.4
  5       2433.4         2933.7         2994.0         1827.4         1077.0
  6       1656.3         1632.3         1636.0         1005.9          616.1
  7       2433.4         2933.7         2994.0         1827.4         1077.0
  8       3812.1         5240.9         5399.4         3263.7         1855.4
  9       3159.6         4010.7         4112.2         2518.5         1488.5
 10       3161.0         4076.3         4185.3         2567.9         1522.1
 11       3877.3         5499.9         5679.8         3437.8         1955.5
 12       2266.3         2935.6         3013.9         1841.5         1080.5
 13        828.1          816.1          818.0          502.9          308.1
 14        167.1           -1.9          -19.9          -14.0           -3.4
 15       -65.2      -258.9      -280.4      -174.1      -100.0
 16        -1.4       -65.6       -73.1       -49.5       -33.6

TIE             TIE SEGMENT DEFLECTION ,IN.
NO.       DIV 1        DIV 2        DIV 3        DIV 4        DIV 5

  1     -.111986     -.125570     -.131303     -.128081     -.124578
  2     -.115537     -.127866     -.133889     -.132564     -.130444
  3     -.134552     -.147288     -.153736     -.152806     -.150914
  4     -.141297     -.155544     -.162109     -.159806     -.156859
  5     -.133080     -.143791     -.149692     -.149842     -.148884
  6     -.140106     -.149043     -.154791     -.156518     -.156796
  7     -.133080     -.143791     -.149692     -.149842     -.148884
  8     -.141297     -.155544     -.162109     -.159806     -.156859
  9     -.134552     -.147288     -.153736     -.152806     -.150914
 10     -.115537     -.127866     -.133889     -.132564     -.130444
 11     -.111986     -.125570     -.131303     -.128081     -.124578
 12     -.093809     -.102740     -.107147     -.106272     -.104797
 13     -.070053     -.074522     -.077395     -.078259     -.078398
 14     -.039272     -.041050     -.042545     -.043570     -.044088
 15     -.029310     -.029974     -.030806     -.031725     -.032281
 16     -.019014     -.019422     -.019847     -.020241     -.020470

      SOIL VERTICAL DISPLACEMENTS AND INCREMENTAL STRESSES

               T = TIE NUMBER (1=CENTER TIE)
             SEG = SEGMENT NUMBER
               Z = DEPTH POINT NUMBER
              XX = DIRECTION PARALLEL TO TIES
              YY = DIRECTION PARALLEL TO RAILS
              ZZ = VERTICAL DIRECTION
              UNITS ARE INCHES AND PSI
              COMPRESSION IS NEGATIVE FOR STRESSES
              DOWNWARD IS POSITIVE FOR DEFLECTIONS


               Z(1) =    6.00 IN.

               Z(2) =   18.00 IN.

               Z(3) =   30.00 IN.

               Z(4) =   54.00 IN.

               Z(5) =  120.00 IN.


T  SEG  Z       W      THETA   S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
---------------------------------------------------------------------------


1   1   1   .10823   -51.8  -13.2    -9.7   -28.9    -1.1    -6.8     -.7
1   1   2   .10336   -20.5   -4.1    -3.7   -12.8      .3    -7.3    -1.9
1   1   3   .09998    -5.5    1.4     1.9    -8.8     1.4    -4.9    -1.7
1   1   4   .08846    -9.5   -1.7    -1.4    -6.3      .4    -2.2    -1.2
1   1   5   .06181    -4.0    -.4     -.3    -3.4      .2     -.9     -.6


1   2   1   .12009   -72.7  -18.7   -12.0   -42.0    -1.0    -2.9     -.9
1   2   2   .11266   -26.3   -4.0    -4.3   -18.0      .2    -4.1    -2.3
1   2   3   .10800    -5.4    3.2     2.5   -11.0     1.1    -3.2    -2.1
1   2   4   .09387   -10.5   -1.6    -1.6    -7.3      .4    -1.7    -1.4
1   2   5   .06375    -4.2    -.3     -.3    -3.6      .1     -.8     -.6
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1    3    1   .12570   -75.1  -19.6  -12.7  -42.8     -.7    1.5   -1.0
1    3    2   .11829   -27.6   -4.7   -4.5  -18.4      .0    -.0   -2.5
1    3    3   .11344    -5.6    3.4    2.7  -11.8      .7   -1.0   -2.3
1    3    4   .09800   -11.3   -1.6   -1.7   -7.9      .3   -1.2   -1.5
1    3    5   .06522    -4.4    -.2    -.3   -3.8      .0    -.6    -.6

1    4    1   .12507   -57.5  -18.2  -11.7  -27.6     -.5    3.5   -1.0
1    4    2   .12037   -25.3   -6.1   -4.4  -14.8     -.0    2.0   -2.5
1    4    3   .11624    -5.9    2.6    2.8  -11.2      .4     .4   -2.3
1    4    4   .10065   -11.7   -1.6   -1.8   -8.3      .2    -.7   -1.5
1    4    5   .06616    -4.4    -.2    -.3   -4.0      .0    -.3    -.7

1    5    1   .12326   -43.4  -16.0  -10.8  -16.6     -.2    1.5    -.9
1    5    2   .12069   -22.8   -7.1   -4.2  -11.5     -.0    1.1   -2.4
1    5    3   .11726    -6.2    1.6    2.8  -10.5      .1     .3   -2.3
1    5    4   .10192   -11.9   -1.7   -1.8   -8.4      .0    -.2   -1.6
1    5    5   .06663    -4.5    -.2    -.3   -4.0      .0    -.1    -.7

T  SEG    Z        W   THETA   S-XX   S-YY   S-ZZ    S-XY   S-XZ   S-YZ
-----------------------------------------------------------------------


2    1    1   .11271   -46.3  -12.2  -10.7  -23.4    -1.8   -5.7     .0
2    1    2   .10898   -20.6   -4.1   -4.9  -11.6     1.5   -7.2    -.0
2    1    3   .10576    -5.8    1.6    1.8   -9.2     3.1   -5.2    -.3
2    1    4   .09317   -10.3   -1.8   -1.5   -7.0      .8   -2.4    -.4
2    1    5   .06371    -4.2    -.4    -.2   -3.6      .2   -1.0    -.2

2    2    1   .12415   -61.8  -17.2  -13.0  -31.6    -1.5   -2.3     .0
2    2    2   .11876   -25.9   -4.0   -6.1  -15.8      .9   -4.1     .0
2    2    3   .11441    -5.7    3.4    2.2  -11.4     2.3   -3.4    -.2
2    2    4   .09905   -11.4   -1.7   -1.6   -8.0      .6   -1.9    -.5
2    2    5   .06573    -4.4    -.3    -.2   -3.9      .2    -.8    -.2

2    3    1   .13013   -63.6  -18.0  -13.8  -31.9    -1.3     .9     .0
2    3    2   .12486   -27.3   -4.7   -6.4  -16.1     -.0    -.4     .0
2    3    3   .12034    -5.9    3.8    2.5  -12.1     1.3   -1.1    -.3
2    3    4   .10355   -12.2   -1.7   -1.8   -8.8      .4   -1.3    -.5
2    3    5   .06729    -4.6    -.2    -.2   -4.1      .1    -.6    -.2

2    4    1   .13067   -50.8  -17.1  -12.9  -20.8     -.9    2.5    -.0
2    4    2   .12743   -25.4   -6.1   -6.0  -13.3     -.5    1.6    -.0
2    4    3   .12349    -6.2    2.9    2.6  -11.7      .5     .2    -.3
2    4    4   .10646   -12.8   -1.8   -1.8   -9.2      .3    -.7    -.5
2    4    5   .06831    -4.7    -.2    -.2   -4.2      .0    -.4    -.2

2    5    1   .12974   -40.5  -15.4  -12.0  -13.0     -.3    1.1    -.0
2    5    2   .12804   -23.3   -7.0   -5.6  -10.7     -.3     .9    -.2
2    5    3   .12469    -6.5    1.9    2.6  -11.1      .1     .3    -.4
2    5    4   .10786   -13.0   -1.8   -1.9   -9.3      .0    -.2    -.5
2    5    5   .06882    -4.7    -.2    -.2   -4.3      .0    -.1    -.2

T  SEG    Z        W   THETA   S-XX   S-YY   S-ZZ    S-XY   S-XZ   S-YZ
-----------------------------------------------------------------------


3    1    1   .13169   -45.9  -12.6   -9.9  -23.4    -2.3   -5.6    -.0
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3    1    2   .12798   -21.2   -4.4   -5.3  -11.6    1.5   -7.1    -.0
3    1    3   .12484    -7.4    1.4     .5   -9.3    3.5   -5.2    -.0
3    1    4   .11237   -11.5   -2.0   -2.1   -7.4    1.0   -2.5    -.0
3    1    5   .08081    -5.1    -.5    -.4   -4.2     .3   -1.1    -.2

3    2    1   .14362   -60.8  -17.5  -12.1  -31.1   -2.0   -2.3    -.0
3    2    2   .13832   -26.4   -4.3   -6.4  -15.7     .8   -4.0    -.2
3    2    3   .13408    -7.4    3.3     .8  -11.5    2.7   -3.4    -.0
3    2    4   .11886   -12.7   -1.9   -2.3   -8.5     .8   -2.1    -.0
3    2    5   .08321    -5.3    -.4    -.5   -4.5     .2    -.9    -.2

3    3    1   .15004   -62.6  -18.4  -12.8  -31.4   -1.6     .9    -.0
3    3    2   .14488   -27.8   -5.1   -6.7  -16.0    -.0    -.4    -.2
3    3    3   .14048    -7.7    3.6     .9  -12.3    1.6   -1.2    -.0
3    3    4   .12384   -13.6   -1.9   -2.5   -9.2     .6   -1.4    -.0
3    3    5   .08507    -5.5    -.3    -.5   -4.8     .2    -.7    -.2

3    4    1   .15095   -49.9  -17.5  -11.9  -20.5   -1.1    2.5    -.0
3    4    2   .14779   -26.0   -6.4   -6.4  -13.2    -.5    1.6    -.0
3    4    3   .14397    -8.1    2.8    1.0  -11.9     .7     .2     .0
3    4    4   .12708   -14.2   -1.9   -2.6   -9.6     .3    -.8    -.0
3    4    5   .08630    -5.7    -.2    -.5   -4.9     .1    -.4    -.2

3    5    1   .15023   -39.7  -15.9  -11.0  -12.8    -.4    1.1     .0
3    5    2   .14859   -23.9   -7.3   -5.9  -10.6    -.3     .9     .0
3    5    3   .14535    -8.4    1.8    1.0  -11.3     .2     .3     .0
3    5    4   .12866   -14.4   -2.0   -2.6   -9.8     .1    -.3    -.0
3    5    5   .08692    -5.7    -.2    -.5   -5.0     .0    -.1    -.2

T  SEG    Z        W   THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
-----------------------------------------------------------------------


4    1    1   .13763   -51.2  -13.8   -9.0  -28.4   -2.0   -6.6     .5
4    1    2   .13292   -21.8   -4.6   -4.5  -12.8     .4   -7.3    1.1
4    1    3   .12963    -8.1    1.2     .0   -9.3    2.3   -5.1     .9
4    1    4   .11776   -11.6   -2.1   -2.4   -7.2     .8   -2.5     .3
4    1    5   .08645    -5.4    -.5    -.5   -4.4     .3   -1.2     .0

4    2    1   .15039   -70.7  -19.4  -11.1  -40.2   -1.7   -2.7     .6
4    2    2   .14336   -27.4   -4.5   -5.2  -17.7     .2   -4.1    1.5
4    2    3   .13884    -8.2    3.0     .3  -11.5    1.8   -3.3    1.1
4    2    4   .12430   -12.8   -1.9   -2.6   -8.3     .7   -2.0     .4
4    2    5   .08899    -5.7    -.4    -.6   -4.7     .2   -1.0     .0

4    3    1   .15687   -72.8  -20.3  -11.7  -40.8   -1.3    1.4     .6
4    3    2   .14991   -28.8   -5.3   -5.5  -18.0     .0    -.2    1.6
4    3    3   .14521    -8.5    3.4     .4  -12.3    1.2   -1.1    1.2
4    3    4   .12932   -13.7   -1.9   -2.8   -9.0     .5   -1.4     .4
4    3    5   .09094    -5.9    -.3    -.6   -4.9     .2    -.7     .0

4    4    1   .15705   -56.1  -19.1  -10.7  -26.2    -.8    3.3     .6
4    4    2   .15268   -26.6   -6.6   -5.3  -14.6    -.0    1.9    1.5
4    4    3   .14868    -8.9    2.5     .4  -11.8     .7     .3    1.2
4    4    4   .13258   -14.3   -1.9   -2.9   -9.4     .3    -.8     .4
4    4    5   .09222    -6.0    -.2    -.6   -5.1     .1    -.5     .0
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4    5   1   .15572    -42.6  -17.0   -9.8  -15.8    -.3    1.4     .6
4    5   2   .15337    -24.2   -7.6   -5.1  -11.5    -.0    1.0    1.4
4    5   3   .15004     -9.2    1.6     .3  -11.1     .2     .3    1.2
4    5   4   .13417    -14.6   -2.0   -3.0   -9.5     .0    -.3     .5
4    5   5   .09285     -6.0    -.2    -.6   -5.2     .0    -.2     .0

T  SEG   Z        W    THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
----------------------------------------------------------------------


5    1   1   .13092    -35.6  -10.5   -7.2  -18.0   -2.7   -4.2     .8
5    1   2   .12815    -17.9   -3.8   -4.9   -9.1    1.2   -5.6    2.0
5    1   3   .12577     -8.4     .9   -1.5   -7.8    3.6   -4.2    1.5
5    1   4   .11560    -11.2   -2.0   -2.5   -6.7    1.1   -2.4     .6
5    1   5   .08592     -5.3    -.5    -.6   -4.3     .4   -1.2     .2

5    2   1   .14121    -46.0  -14.5   -8.7  -22.9   -2.3   -1.6    1.1
5    2   2   .13739    -21.9   -3.9   -5.9  -12.1     .7   -3.1    2.6
5    2   3   .13420     -8.6    2.5   -1.5   -9.5    2.8   -2.8    1.9
5    2   4   .12182    -12.3   -1.8   -2.8   -7.6     .9   -1.9     .6
5    2   5   .08840     -5.6    -.4    -.6   -4.6     .3   -1.0     .3

5    3   1   .14713    -47.2  -15.2   -9.1  -22.9   -1.8     .7    1.2
5    3   2   .14347    -22.9   -4.5   -6.2  -12.2     .0    -.4    2.8
5    3   3   .14017     -8.9    2.8   -1.6  -10.1    1.8   -1.0    2.0
5    3   4   .12662    -13.1   -1.8   -3.0   -8.3     .7   -1.3     .7
5    3   5   .09031     -5.8    -.3    -.6   -4.8     .2    -.7     .3

5    4   1   .14864    -37.9  -14.7   -8.4  -14.9   -1.2    1.8    1.0
5    4   2   .14645    -21.7   -5.5   -5.9  -10.2    -.4    1.1    2.6
5    4   3   .14358     -9.4    2.2   -1.7   -9.9     .9     .0    1.9
5    4   4   .12978    -13.7   -1.8   -3.2   -8.7     .4    -.8     .7
5    4   5   .09160     -5.9    -.2    -.7   -5.0     .1    -.4     .3

5    5   1   .14854    -30.5  -13.5   -7.7   -9.3    -.4     .8     .9
5    5   2   .14747    -20.2   -6.3   -5.6   -8.3    -.2     .6    2.3
5    5   3   .14502     -9.7    1.5   -1.7   -9.5     .2     .2    1.8
5    5   4   .13134    -13.9   -1.9   -3.2   -8.8     .1    -.2     .7
5    5   5   .09225     -6.0    -.2    -.7   -5.1     .0    -.2     .3

T  SEG   Z        W    THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
----------------------------------------------------------------------


6    1   1   .13873    -26.3   -8.7   -5.4  -12.2   -3.3   -2.8     .0
6    1   2   .13706    -15.7   -3.6   -5.3   -6.9    1.3   -4.4     .0
6    1   3   .13530     -9.5     .6   -3.2   -6.9    4.3   -3.7     .0
6    1   4   .12634    -11.6   -2.0   -3.0   -6.6    1.3   -2.3     .0
6    1   5   .09661     -5.8    -.5    -.8   -4.6     .5   -1.3     .0

6    2   1   .14785    -31.4  -11.9   -6.4  -13.1   -2.8    -.9     .0
6    2   2   .14587    -18.7   -3.7   -6.3   -8.7     .7   -2.5     .0
6    2   3   .14358     -9.8    2.0   -3.6   -8.3    3.3   -2.5     .0
6    2   4   .13270    -12.7   -1.9   -3.3   -7.5    1.1   -1.9     .0
6    2   5   .09927     -6.1    -.4    -.8   -4.9     .4   -1.0     .0

6    3   1   .15368    -31.9  -12.5   -6.7  -12.7   -2.2     .3     .0
6    3   2   .15191    -19.5   -4.3   -6.6   -8.7     .0    -.5     .0
```

6	3	3	.14956	-10.3	2.3	-3.8	-8.8	2.1	-1.0	.0
6	3	4	.13764	-13.5	-1.8	-3.6	-8.1	.8	-1.4	.0
6	3	5	.10135	-6.3	-.3	-.9	-5.1	.3	-.8	.0
6	4	1	.15615	-26.9	-12.4	-6.1	-8.4	-1.4	.9	.0
6	4	2	.15522	-18.9	-5.0	-6.4	-7.4	-.4	.6	.0
6	4	3	.15313	-10.8	1.9	-3.9	-8.7	1.0	-.1	.0
6	4	4	.14092	-14.1	-1.9	-3.7	-8.5	.5	-.8	.0
6	4	5	.10276	-6.5	-.2	-.9	-5.3	.2	-.5	.0
6	5	1	.15686	-22.9	-11.8	-5.7	-5.4	-.5	.4	.0
6	5	2	.15654	-18.0	-5.6	-6.1	-6.3	-.2	.4	.0
6	5	3	.15471	-11.1	1.3	-4.0	-8.4	.3	.0	.0
6	5	4	.14255	-14.3	-1.9	-3.8	-8.6	.2	-.3	.0
6	5	5	.10348	-6.5	-.2	-.9	-5.4	.0	-.2	.0

T	SEG	Z	W	THETA	S-XX	S-YY	S-ZZ	S-XY	S-XZ	S-YZ
7	1	1	.13092	-35.6	-10.5	-7.2	-18.0	-2.7	-4.2	-.8
7	1	2	.12815	-17.9	-3.8	-4.9	-9.1	1.2	-5.6	-2.0
7	1	3	.12577	-8.4	.9	-1.5	-7.8	3.6	-4.2	-1.5
7	1	4	.11560	-11.2	-2.0	-2.5	-6.7	1.1	-2.4	-.6
7	1	5	.08592	-5.3	-.5	-.6	-4.3	.4	-1.2	-.2
7	2	1	.14121	-46.0	-14.5	-8.7	-22.9	-2.3	-1.6	-1.1
7	2	2	.13739	-21.9	-3.9	-5.9	-12.1	.7	-3.1	-2.6
7	2	3	.13420	-8.6	2.5	-1.5	-9.5	2.8	-2.8	-1.9
7	2	4	.12182	-12.3	-1.8	-2.8	-7.6	.9	-1.9	-.6
7	2	5	.08840	-5.6	-.4	-.6	-4.6	.3	-1.0	-.3
7	3	1	.14713	-47.2	-15.2	-9.1	-22.9	-1.8	.7	-1.2
7	3	2	.14347	-22.9	-4.5	-6.2	-12.2	.0	-.4	-2.8
7	3	3	.14017	-8.9	2.8	-1.6	-10.1	1.8	-1.0	-2.0
7	3	4	.12662	-13.1	-1.8	-3.0	-8.3	.7	-1.3	-.7
7	3	5	.09031	-5.8	-.3	-.6	-4.8	.2	-.7	-.3
7	4	1	.14864	-37.9	-14.7	-8.4	-14.9	-1.2	1.8	-1.0
7	4	2	.14645	-21.7	-5.5	-5.9	-10.2	-.4	1.1	-2.6
7	4	3	.14358	-9.4	2.2	-1.7	-9.9	.9	.0	-1.9
7	4	4	.12978	-13.7	-1.8	-3.2	-8.7	.4	-.8	-.7
7	4	5	.09160	-5.9	-.2	-.7	-5.0	.1	-.4	-.3
7	5	1	.14854	-30.5	-13.5	-7.7	-9.3	-.4	.8	-.9
7	5	2	.14747	-20.2	-6.3	-5.6	-8.3	-.2	.6	-2.3
7	5	3	.14502	-9.7	1.5	-1.7	-9.5	.2	.2	-1.8
7	5	4	.13134	-13.9	-1.9	-3.2	-8.8	.1	-.2	-.7
7	5	5	.09225	-6.0	-.2	-.7	-5.1	.0	-.2	-.3

T	SEG	Z	W	THETA	S-XX	S-YY	S-ZZ	S-XY	S-XZ	S-YZ
8	1	1	.13763	-51.2	-13.8	-9.0	-28.4	-2.0	-6.6	-.5
8	1	2	.13292	-21.8	-4.6	-4.5	-12.8	.4	-7.3	-1.1
8	1	3	.12963	-8.1	1.2	.0	-9.3	2.3	-5.1	-.9
8	1	4	.11776	-11.6	-2.1	-2.4	-7.2	.8	-2.5	-.3

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8    1    5    .08645     -5.4     -.5     -.5    -4.4      .3    -1.2     -.0

8    2    1    .15039    -70.7   -19.4   -11.1   -40.2    -1.7    -2.7     -.6
8    2    2    .14336    -27.4    -4.5    -5.2   -17.7      .2    -4.1    -1.5
8    2    3    .13884     -8.2     3.0      .3   -11.5     1.8    -3.3    -1.1
8    2    4    .12430    -12.8    -1.9    -2.6    -8.3      .7    -2.0     -.4
8    2    5    .08899     -5.7     -.4     -.6    -4.7      .2    -1.0     -.0

8    3    1    .15687    -72.8   -20.3   -11.7   -40.8    -1.3     1.4     -.6
8    3    2    .14991    -28.8    -5.3    -5.5   -18.0      .0     -.2    -1.6
8    3    3    .14521     -8.5     3.4      .4   -12.3     1.2    -1.1    -1.2
8    3    4    .12932    -13.7    -1.9    -2.8    -9.0      .5    -1.4     -.4
8    3    5    .09094     -5.9     -.3     -.6    -4.9      .2     -.7     -.0

8    4    1    .15705    -56.1   -19.1   -10.7   -26.2     -.8     3.3     -.6
8    4    2    .15268    -26.6    -6.6    -5.3   -14.6     -.0     1.9    -1.5
8    4    3    .14868     -8.9     2.5      .4   -11.8      .7      .3    -1.2
8    4    4    .13258    -14.3    -1.9    -2.9    -9.4      .3     -.8     -.4
8    4    5    .09222     -6.0     -.2     -.6    -5.1      .1     -.5     -.0

8    5    1    .15572    -42.6   -17.0    -9.8   -15.8     -.3     1.4     -.6
8    5    2    .15337    -24.2    -7.6    -5.1   -11.5     -.0     1.0    -1.4
8    5    3    .15004     -9.2     1.6      .3   -11.1      .2      .3    -1.2
8    5    4    .13417    -14.6    -2.0    -3.0    -9.5      .0     -.3     -.5
8    5    5    .09285     -6.0     -.2     -.6    -5.2      .0     -.2     -.0

T  SEG    Z         W    THETA    S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
------------------------------------------------------------------------------


9    1    1    .13169    -45.9   -12.6    -9.9   -23.4    -2.3    -5.6      .0
9    1    2    .12798    -21.2    -4.4    -5.3   -11.6     1.5    -7.1      .0
9    1    3    .12484     -7.4     1.4      .5    -9.3     3.5    -5.2      .0
9    1    4    .11237    -11.5    -2.0    -2.1    -7.4     1.0    -2.5      .0
9    1    5    .08081     -5.1     -.5     -.4    -4.2      .3    -1.1      .2

9    2    1    .14362    -60.8   -17.5   -12.1   -31.1    -2.0    -2.3      .0
9    2    2    .13832    -26.4    -4.3    -6.4   -15.7      .8    -4.0      .2
9    2    3    .13408     -7.4     3.3      .8   -11.5     2.7    -3.4      .0
9    2    4    .11886    -12.7    -1.9    -2.3    -8.5      .8    -2.1      .0
9    2    5    .08321     -5.3     -.4     -.5    -4.5      .2     -.9      .2

9    3    1    .15004    -62.6   -18.4   -12.8   -31.4    -1.6      .9      .0
9    3    2    .14488    -27.8    -5.1    -6.7   -16.0     -.0     -.4      .2
9    3    3    .14048     -7.7     3.6      .9   -12.3     1.6    -1.2      .0
9    3    4    .12384    -13.6    -1.9    -2.5    -9.2      .6    -1.4      .0
9    3    5    .08507     -5.5     -.3     -.5    -4.8      .2     -.7      .2

9    4    1    .15095    -49.9   -17.5   -11.9   -20.5    -1.1     2.5      .0
9    4    2    .14779    -26.0    -6.4    -6.4   -13.2     -.5     1.6      .0
9    4    3    .14397     -8.1     2.8     1.0   -11.9      .7      .2      .0
9    4    4    .12708    -14.2    -1.9    -2.6    -9.6      .3     -.8      .0
9    4    5    .08630     -5.7     -.2     -.5    -4.9      .1     -.4      .2

9    5    1    .15023    -39.7   -15.9   -11.0   -12.8     -.4     1.1     -.0
9    5    2    .14859    -23.9    -7.3    -5.9   -10.6     -.3      .9     -.0
9    5    3    .14535     -8.4     1.8     1.0   -11.3      .2      .3     -.0
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  9    5    4   .12866    -14.4    -2.0    -2.6    -9.8      .1     -.3      .0
  9    5    5   .08692     -5.7     -.2     -.5    -5.0      .0     -.1      .2

  T   SEG   Z       W      THETA    S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
--------------------------------------------------------------------------------


 10    1    1   .11271    -46.3   -12.2   -10.7   -23.4    -1.8    -5.7      .0
 10    1    2   .10898    -20.6    -4.1    -4.9   -11.6     1.5    -7.2      .0
 10    1    3   .10576     -5.8     1.6     1.8    -9.2     3.1    -5.2      .3
 10    1    4   .09317    -10.3    -1.8    -1.5    -7.0      .8    -2.4      .4
 10    1    5   .06371     -4.2     -.4     -.2    -3.6      .2    -1.0      .2

 10    2    1   .12415    -61.8   -17.2   -13.0   -31.6    -1.5    -2.3     -.0
 10    2    2   .11876    -25.9    -4.0    -6.1   -15.8      .9    -4.1     -.0
 10    2    3   .11441     -5.7     3.4     2.2   -11.4     2.3    -3.4      .2
 10    2    4   .09905    -11.4    -1.7    -1.6    -8.0      .6    -1.9      .5
 10    2    5   .06573     -4.4     -.3     -.2    -3.9      .2     -.8      .2

 10    3    1   .13013    -63.6   -18.0   -13.8   -31.9    -1.3      .9     -.0
 10    3    2   .12486    -27.3    -4.7    -6.4   -16.1     -.0     -.4     -.0
 10    3    3   .12034     -5.9     3.8     2.5   -12.1     1.3    -1.1      .3
 10    3    4   .10355    -12.2    -1.7    -1.8    -8.8      .4    -1.3      .5
 10    3    5   .06729     -4.6     -.2     -.2    -4.1      .1     -.6      .2

 10    4    1   .13067    -50.8   -17.1   -12.9   -20.8     -.9     2.5      .0
 10    4    2   .12743    -25.4    -6.1    -6.0   -13.3     -.5     1.6      .0
 10    4    3   .12349     -6.2     2.9     2.6   -11.7      .5      .2      .3
 10    4    4   .10646    -12.8    -1.8    -1.8    -9.2      .3     -.7      .5
 10    4    5   .06831     -4.7     -.2     -.2    -4.2      .0     -.4      .2

 10    5    1   .12974    -40.5   -15.4   -12.0   -13.0     -.3     1.1      .0
 10    5    2   .12804    -23.3    -7.0    -5.6   -10.7     -.3      .9      .2
 10    5    3   .12469     -6.5     1.9     2.6   -11.1      .1      .3      .4
 10    5    4   .10786    -13.0    -1.8    -1.9    -9.3      .0     -.2      .5
 10    5    5   .06882     -4.7     -.2     -.2    -4.3      .0     -.1      .2

  T   SEG   Z       W      THETA    S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
--------------------------------------------------------------------------------


 11    1    1   .10823    -51.8   -13.2    -9.7   -28.9    -1.1    -6.8      .7
 11    1    2   .10336    -20.5    -4.1    -3.7   -12.8      .3    -7.3     1.9
 11    1    3   .09998     -5.5     1.4     1.9    -8.8     1.4    -4.9     1.7
 11    1    4   .08846     -9.5    -1.7    -1.4    -6.3      .4    -2.2     1.2
 11    1    5   .06181     -4.0     -.4     -.3    -3.4      .2     -.9      .6

 11    2    1   .12009    -72.7   -18.7   -12.0   -42.0    -1.0    -2.9      .9
 11    2    2   .11266    -26.3    -4.0    -4.3   -18.0      .2    -4.1     2.3
 11    2    3   .10800     -5.4     3.2     2.5   -11.0     1.1    -3.2     2.1
 11    2    4   .09387    -10.5    -1.6    -1.6    -7.3      .4    -1.7     1.4
 11    2    5   .06375     -4.2     -.3     -.3    -3.6      .1     -.8      .6

 11    3    1   .12570    -75.1   -19.6   -12.7   -42.8     -.7     1.5     1.0
 11    3    2   .11829    -27.6    -4.7    -4.5   -18.4      .0     -.0     2.5
 11    3    3   .11344     -5.6     3.4     2.7   -11.8      .7    -1.0     2.3
 11    3    4   .09800    -11.3    -1.6    -1.7    -7.9      .3    -1.2     1.5
 11    3    5   .06522     -4.4     -.2     -.3    -3.8      .0     -.6      .6
 11    4    1    .12507    -57.5   -18.2   -11.7   -27.6      -.5     3.5     1.0
 11    4    2    .12037    -25.3    -6.1    -4.4   -14.8      -.0     2.0     2.5
 11    4    3    .11624     -5.9     2.6     2.8   -11.2       .4      .4     2.3
 11    4    4    .10065    -11.7    -1.6    -1.8    -8.3       .2     -.7     1.5
 11    4    5    .06616     -4.4     -.2     -.3    -4.0       .0     -.3      .7

 11    5    1    .12326    -43.4   -16.0   -10.8   -16.6      -.2     1.5      .9
 11    5    2    .12069    -22.8    -7.1    -4.2   -11.5      -.0     1.1     2.4
 11    5    3    .11726     -6.2     1.6     2.8   -10.5       .1      .3     2.3
 11    5    4    .10192    -11.9    -1.7    -1.8    -8.4       .0     -.2     1.6
 11    5    5    .06663     -4.5     -.2     -.3    -4.0       .0     -.1      .7

  T  SEG    Z       W      THETA    S-XX    S-YY    S-ZZ     S-XY    S-XZ    S-YZ
 ---------------------------------------------------------------------------------


 12    1    1    .09172    -32.2    -8.8    -6.6   -16.8     -1.5    -4.0     1.5
 12    1    2    .08901    -14.6    -3.0    -3.4    -8.2       .9    -4.9     3.9
 12    1    3    .08683     -5.2      .9      .2    -6.4      2.2    -3.5     3.2
 12    1    4    .07851     -7.9    -1.4    -1.5    -5.0       .6    -1.7     1.8
 12    1    5    .05714     -3.6     -.3     -.3    -2.9       .2     -.8      .8

 12    2    1    .10000    -43.1   -12.3    -8.1   -22.7     -1.3    -1.6     2.0
 12    2    2    .09608    -18.3    -3.0    -4.2   -11.1       .5    -2.8     5.0
 12    2    3    .09313     -5.2     2.2      .4    -7.9      1.7    -2.3     4.0
 12    2    4    .08294     -8.7    -1.3    -1.7    -5.7       .5    -1.4     2.0
 12    2    5    .05882     -3.8     -.3     -.4    -3.1       .2     -.7      .9

 12    3    1    .10438    -44.3   -12.9    -8.5   -22.9     -1.1      .7     2.1
 12    3    2    .10055    -19.2    -3.5    -4.4   -11.3      -.0     -.2     5.3
 12    3    3    .09748     -5.4     2.4      .5    -8.4      1.0     -.8     4.3
 12    3    4    .08634     -9.3    -1.3    -1.8    -6.2       .4    -1.0     2.2
 12    3    5    .06012     -3.9     -.2     -.4    -3.3       .1     -.5      .9

 12    4    1    .10486    -35.0   -12.2    -7.9   -14.9      -.7     1.8     2.0
 12    4    2    .10249    -17.9    -4.4    -4.1    -9.3      -.3     1.1     5.1
 12    4    3    .09985     -5.7     1.8      .5    -8.1       .5      .2     4.3
 12    4    4    .08855     -9.7    -1.3    -1.9    -6.5       .2     -.5     2.3
 12    4    5    .06098     -4.0     -.2     -.4    -3.4       .0     -.3     1.0

 12    5    1    .10426    -27.5   -11.0    -7.2    -9.2      -.3      .8     1.8
 12    5    2    .10300    -16.4    -5.1    -3.9    -7.4      -.2      .6     4.7
 12    5    3    .10077     -5.9     1.2      .5    -7.7       .1      .2     4.1
 12    5    4    .08963     -9.9    -1.4    -1.9    -6.6       .0     -.2     2.3
 12    5    5    .06140     -4.0     -.1     -.4    -3.5       .0     -.1     1.0

  T  SEG    Z       W      THETA    S-XX    S-YY    S-ZZ     S-XY    S-XZ    S-YZ
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 13    1    1    .06937    -13.2    -4.4    -2.7    -6.1     -1.6    -1.4     1.3
 13    1    2    .06853     -7.9    -1.8    -2.6    -3.4       .7    -2.2     3.3
 13    1    3    .06765     -4.8      .3    -1.6    -3.5      2.1    -1.8     2.9
 13    1    4    .06317     -5.8    -1.0    -1.5    -3.3       .7    -1.2     1.8
 13    1    5    .04830     -2.9     -.2     -.4    -2.3       .2     -.6      .9
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13   2   1   .07392   -15.7   -5.9   -3.2   -6.6   -1.4    -.5    1.6
13   2   2   .07294    -9.3   -1.9   -3.1   -4.3     .4   -1.2    4.1
13   2   3   .07179    -4.9    1.0   -1.8   -4.1    1.7   -1.2    3.5
13   2   4   .06635    -6.3    -.9   -1.7   -3.7     .5   -1.0    2.0
13   2   5   .04964    -3.0    -.2    -.4   -2.4     .2    -.5     .9

13   3   1   .07684   -16.0   -6.3   -3.3   -6.4   -1.1     .1    1.8
13   3   2   .07596    -9.8   -2.1   -3.3   -4.3     .0    -.2    4.5
13   3   3   .07478    -5.1    1.2   -1.9   -4.4    1.1    -.5    3.8
13   3   4   .06882    -6.8    -.9   -1.8   -4.1     .4    -.7    2.2
13   3   5   .05067    -3.2    -.2    -.4   -2.6     .1    -.4    1.0

13   4   1   .07807   -13.5   -6.2   -3.1   -4.2    -.7     .5    1.7
13   4   2   .07761    -9.4   -2.5   -3.2   -3.7    -.2     .3    4.3
13   4   3   .07656    -5.4     .9   -2.0   -4.3     .5    -.0    3.8
13   4   4   .07046    -7.0    -.9   -1.9   -4.2     .2    -.4    2.3
13   4   5   .05138    -3.2    -.1    -.4   -2.7     .0    -.2    1.0

13   5   1   .07843   -11.5   -5.9   -2.8   -2.7    -.2     .2    1.6
13   5   2   .07827    -9.0   -2.8   -3.0   -3.2    -.1     .2    4.1
13   5   3   .07736    -5.5     .7   -2.0   -4.2     .1     .0    3.8
13   5   4   .07128    -7.2   -1.0   -1.9   -4.3     .0    -.1    2.3
13   5   5   .05174    -3.3    -.1    -.4   -2.7     .0    -.0    1.0

 T  SEG  Z      W     THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
-----------------------------------------------------------------------

14   1   1   .03921    -3.5   -1.7    -.6   -1.2   -1.1    -.2     .7
14   1   2   .03914    -3.3    -.8   -1.5   -1.0     .3    -.6    1.9
14   1   3   .03894    -3.2     .0   -1.7   -1.4    1.4    -.7    1.7
14   1   4   .03710    -3.3    -.6   -1.0   -1.7     .4    -.6    1.2
14   1   5   .02878    -1.7    -.1    -.2   -1.4     .2    -.4     .6

14   2   1   .04121    -3.0   -2.2    -.6    -.2   -1.0     .0     .9
14   2   2   .04131    -3.6    -.9   -1.7   -1.0     .2    -.4    2.3
14   2   3   .04108    -3.3     .3   -2.0   -1.6    1.1    -.5    2.1
14   2   4   .03888    -3.6    -.5   -1.1   -1.9     .4    -.5    1.4
14   2   5   .02957    -1.8    -.1    -.3   -1.5     .1    -.3     .6

14   3   1   .04275    -2.9   -2.4    -.6     .0    -.7    -.0    1.0
14   3   2   .04292    -3.7   -1.0   -1.8    -.9     .0    -.2    2.5
14   3   3   .04269    -3.5     .4   -2.1   -1.7     .7    -.3    2.3
14   3   4   .04028    -3.8    -.5   -1.2   -2.1     .3    -.4    1.5
14   3   5   .03019    -1.9    -.0    -.3   -1.5     .0    -.2     .6

14   4   1   .04378    -3.0   -2.5    -.5     .0    -.5    -.0    1.0
14   4   2   .04396    -3.8   -1.1   -1.8    -.9    -.0    -.0    2.5
14   4   3   .04374    -3.6     .4   -2.2   -1.8     .4    -.1    2.3
14   4   4   .04123    -4.0    -.5   -1.3   -2.2     .2    -.2    1.5
14   4   5   .03062    -1.9    -.0    -.3   -1.6     .0    -.1     .7

14   5   1   .04429    -3.0   -2.5    -.5    -.0    -.2    -.0     .9
14   5   2   .04446    -3.8   -1.2   -1.8    -.9    -.0     .0    2.4
14   5   3   .04424    -3.7     .3   -2.2   -1.8     .1    -.0    2.3
14   5   4   .04171    -4.1    -.5   -1.3   -2.3     .0    -.0    1.6
14   5   5   .03084    -1.9    -.0    -.3   -1.6     .0    -.0     .7
```

```
 T  SEG  Z        W      THETA    S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
------------------------------------------------------------------------------


15   1   1   .02940        .6     -.6      .6      .5     -.9      .2      .3
15   1   2   .02956      -1.3     -.5     -.8      .0      .0      .0      .7
15   1   3   .02965      -2.6     -.2    -1.9     -.5      .9     -.2      .8
15   1   4   .02930      -2.2     -.4     -.9     -.9      .3     -.3      .9
15   1   5   .02464      -1.4     -.1     -.3    -1.0      .1     -.3      .6

15   2   1   .03030       2.0     -.7      .8     1.8     -.7      .2      .3
15   2   2   .03070      -1.2     -.5     -.9      .3      .0      .0      .8
15   2   3   .03084      -2.8     -.1    -2.1     -.5      .7     -.1     1.0
15   2   4   .03043      -2.3     -.3    -1.0    -1.0      .3     -.3     1.0
15   2   5   .02525      -1.5     -.0     -.3    -1.1      .1     -.2      .6

15   3   1   .03118       2.3     -.7     1.0     2.1     -.6     -.0      .3
15   3   2   .03162      -1.2     -.6    -1.0      .3      .0     -.0      .9
15   3   3   .03178      -2.9     -.0    -2.3     -.5      .5     -.1     1.0
15   3   4   .03132      -2.5     -.3    -1.1    -1.1      .2     -.2     1.0
15   3   5   .02572      -1.5     -.0     -.3    -1.1      .0     -.2      .6

15   4   1   .03198       1.5     -.9     1.0     1.3     -.3     -.2      .4
15   4   2   .03231      -1.3     -.6    -1.0      .2     -.0     -.1      .9
15   4   3   .03244      -3.0     -.0    -2.4     -.6      .3     -.0     1.1
15   4   4   .03194      -2.6     -.3    -1.1    -1.1      .1     -.1     1.1
15   4   5   .02606      -1.5     -.0     -.3    -1.1      .0     -.1      .6

15   5   1   .03246        .8    -1.0     1.0      .8     -.1     -.0      .4
15   5   2   .03268      -1.5     -.5    -1.0      .0      .0     -.0     1.0
15   5   3   .03278      -3.1      .0    -2.5     -.6      .0     -.0     1.1
15   5   4   .03225      -2.6     -.3    -1.2    -1.1      .0     -.0     1.1
15   5   5   .02623      -1.6     -.0     -.3    -1.2      .0     -.0      .7

 T  SEG  Z        W      THETA    S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
------------------------------------------------------------------------------


16   1   1   .01898        .4     -.3      .7      .0     -.5      .0      .0
16   1   2   .01900       -.6     -.3     -.3      .0     -.0      .0      .1
16   1   3   .01908      -1.6     -.2    -1.3     -.1      .4     -.0      .3
16   1   4   .01920      -1.2     -.2     -.6     -.4      .2     -.2      .5
16   1   5   .01709       -.9     -.0     -.2     -.6      .1     -.2      .4

16   2   1   .01947        .9     -.4      .9      .4     -.4      .0      .0
16   2   2   .01956       -.5     -.3     -.3      .1     -.0      .0      .1
16   2   3   .01967      -1.7     -.2    -1.4     -.1      .3     -.0      .3
16   2   4   .01981      -1.3     -.2     -.7     -.4      .2     -.1      .5
16   2   5   .01748      -1.0     -.0     -.3     -.6      .0     -.1      .4

16   3   1   .01991       1.1     -.4     1.0      .5     -.3      .0      .0
16   3   2   .02002       -.5     -.3     -.3      .1     -.0      .0      .1
16   3   3   .02014      -1.8     -.1    -1.5     -.1      .3     -.0      .3
16   3   4   .02029      -1.3     -.2     -.7     -.4      .1     -.1      .6
16   3   5   .01778      -1.0     -.0     -.3     -.7      .0     -.1      .5

16   4   1   .02028        .9     -.5     1.0      .4     -.2     -.0      .0
```

```
16   4   2   .02037     -.6     -.3    -.4     .0      .0     -.0      .1
16   4   3   .02048    -1.9     -.1   -1.6    -.1      .2     -.0      .3
16   4   4   .02062    -1.4     -.2    -.8    -.5      .0     -.0      .6
16   4   5   .01799    -1.0     -.0    -.3    -.7      .0     -.0      .5

16   5   1   .02050      .8     -.5    1.0     .3     -.0     -.0      .0
16   5   2   .02056     -.6     -.3    -.4     .0      .0     -.0      .2
16   5   3   .02066    -1.9     -.0   -1.6    -.2      .0     -.0      .4
16   5   4   .02079    -1.4     -.2    -.8    -.5      .0     -.0      .6
16   5   5   .01809    -1.0     -.0    -.3    -.7      .0     -.0      .5

              SUPERIMPOSED RESULTS FROM CALC. STEP NO.  2

                ----- DEFLECTIONS AND REACTIONS ----

       TIE     DEFLECTION        REACTION       DEFLECTION
       NO.        RAIL           RAIL SEAT          TIE
                  IN.               LBS             IN.

         1     -.077016          3273.3         -.076549
         2     -.072315          -750.7         -.072422
         3     -.163815         19571.6         -.161019
         4     -.154584         15289.5         -.152400
         5     -.165250         14634.1         -.163160
         6     -.267020         40900.3         -.261177
         7     -.165250         14634.1         -.163160
         8     -.154584         15289.5         -.152400
         9     -.163815         19571.6         -.161019
        10     -.072315          -750.7         -.072422
        11     -.077016          3273.3         -.076549
        12     -.107872         11137.7         -.106281
        13     -.133510         20450.2         -.130589
        14     -.057378          3496.4         -.056879
        15     -.077567         12016.3         -.075851
        16     -.091500         20322.3         -.088597

               TIE CENTER     TIE RAIL-SEAT       RAIL
       TIE      BENDING         BENDING          BENDING
       NO.      MOMENT          MOMENT           MOMENT
               (IN.-LBS)       (IN.-LBS)        (IN.-LBS)

         1      .48475E+06      .96515E+05      .12462E+08
         2      .46663E+06      .76208E+05      .11245E+08
         3     -.14062E+06      .75787E+05      .10012E+08
         4      .10621E+06      .93881E+05      .91705E+07
         5     -.10731E+06      .57426E+05      .76470E+07
         6     -.10171E+07      .36872E+05      .64162E+07
         7     -.10731E+06      .57426E+05      .60034E+07
         8      .10621E+06      .93881E+05      .58832E+07
         9     -.14062E+06      .75787E+05      .50809E+07
        10      .46663E+06      .76208E+05      .46700E+07
        11      .48475E+06      .96515E+05      .42441E+07
        12     -.10593E+05      .54717E+05      .28956E+07
        13     -.50856E+06      .18436E+05      .17699E+07
        14     -.96717E+05      .27086E+04      .10532E+07
        15     -.37854E+06     -.26339E+04      .40645E+06
        16     -.60725E+06     -.42089E+03      .00000E+00

       TIE            TIE/SOIL REACTIONS, LBS
       NO.       DIV 1        DIV 2        DIV 3        DIV 4        DIV 5
```

```
          1        3877.3         5499.9         5679.8         3437.8         1955.5
          2        3161.0         4076.3         4185.3         2567.9         1522.1
          3        3159.6         4010.7         4112.2         2518.5         1488.5
          4        3812.1         5240.9         5399.4         3263.7         1855.4
          5        2433.4         2933.7         2994.0         1827.4         1077.0
          6        1656.3         1632.3         1636.0         1005.9          616.1
          7        2433.4         2933.7         2994.0         1827.4         1077.0
          8        3812.1         5240.9         5399.4         3263.7         1855.4
          9        3159.6         4010.7         4112.2         2518.5         1488.5
         10        3161.0         4076.3         4185.3         2567.9         1522.1
         11        3877.3         5499.9         5679.8         3437.8         1955.5
         12        2266.3         2935.6         3013.9         1841.5         1080.5
         13         828.1          816.1          818.0          502.9          308.1
         14         167.1           -1.9          -19.9          -14.0           -3.4
         15         -65.2         -258.9         -280.4         -174.1         -100.0
         16          -1.4          -65.6          -73.1          -49.5          -33.6

        TIE              TIE SEGMENT DEFLECTION ,IN.
        NO.         DIV 1          DIV 2          DIV 3          DIV 4          DIV 5

          1      -.057946       -.071530       -.077263       -.074041       -.070538
          2      -.055230       -.067559       -.073582       -.072257       -.070137
          3      -.143171       -.155908       -.162356       -.161425       -.159533
          4      -.132677       -.146924       -.153490       -.151187       -.148239
          5      -.147967       -.158677       -.164579       -.164729       -.163771
          6      -.248186       -.257123       -.262870       -.264597       -.264876
          7      -.147967       -.158677       -.164579       -.164729       -.163771
          8      -.132677       -.146924       -.153490       -.151187       -.148239
          9      -.143171       -.155908       -.162356       -.161425       -.159533
         10      -.055230       -.067559       -.073582       -.072257       -.070137
         11      -.057946       -.071530       -.077263       -.074041       -.070538
         12      -.093809       -.102740       -.107147       -.106272       -.104797
         13      -.124093       -.128562       -.131435       -.132299       -.132438
         14      -.054158       -.055937       -.057432       -.058457       -.058975
         15      -.074731       -.075394       -.076227       -.077145       -.077701
         16      -.087941       -.088349       -.088774       -.089168       -.089396

           SOIL VERTICAL DISPLACEMENTS AND INCREMENTAL STRESSES

                    T = TIE NUMBER (1=CENTER TIE)
                  SEG = SEGMENT NUMBER
                    Z = DEPTH POINT NUMBER
                   XX = DIRECTION PARALLEL TO TIES
                   YY = DIRECTION PARALLEL TO RAILS
                   ZZ = VERTICAL DIRECTION
                   UNITS ARE INCHES AND PSI
                   COMPRESSION IS NEGATIVE FOR STRESSES
                   DOWNWARD IS POSITIVE FOR DEFLECTIONS

                    Z(1) =    1.00 IN.

                    Z(2) =   37.00 IN.

 T  SEG  Z        W      THETA   S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
-------------------------------------------------------------------------------


 1   1   1   .11161    -96.2  -29.2   -32.5   -34.5    -2.0     -.5     -.1
 1   1   2   .09766    -12.6   -2.5    -2.3    -7.7      .5    -2.7    -1.3


 1   2   1   .12501   -135.5  -41.6   -44.5   -49.3    -1.6     -.3     -.1
```

```
1   2   2   .10504   -14.4   -2.4   -2.7   -9.3     .4   -2.0   -1.3

1   3   1   .13074  -140.9  -43.5  -46.3  -51.1   -1.0    -.0    -.2
1   3   2   .11024   -15.5   -2.6   -2.9  -10.0     .3   -1.1   -1.6

1   4   1   .12779   -94.0  -29.3  -33.5  -31.2    -.5     .0    -.2
1   4   2   .11314   -16.1   -3.0   -3.0  -10.1     .2    -.4   -1.7

1   5   1   .12447   -61.8  -19.4  -24.4  -18.0    -.1     .0    -.2
1   5   2   .11433   -16.2   -3.3   -3.0  -10.0     .0    -.0   -1.7

T SEG   Z        W   THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
--------------------------------------------------------------------

2   1   1   .11527   -81.6  -26.0  -27.8  -27.8   -4.4    -.4    -.0
2   1   2   .10329   -13.8   -2.8   -2.6   -8.4    1.1   -3.0    -.3

2   2   1   .12751  -106.0  -34.7  -35.1  -36.3   -3.2    -.2    -.0
2   2   2   .11129   -15.7   -2.7   -3.0  -10.0     .9   -2.2    -.4

2   3   1   .13353  -110.2  -36.3  -36.5  -37.4   -1.6    -.1    -.0
2   3   2   .11697   -16.9   -2.9   -3.3  -10.8     .5   -1.2    -.4

2   4   1   .13241   -76.8  -25.8  -27.7  -23.3    -.4     .0    -.0
2   4   2   .12020   -17.6   -3.3   -3.3  -11.0     .2    -.5    -.4

2   5   1   .13041   -54.3  -18.5  -21.7  -14.1    -.0     .0    -.0
2   5   2   .12154   -17.8   -3.6   -3.4  -10.8     .0    -.0    -.5

T SEG   Z        W   THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
--------------------------------------------------------------------

3   1   1   .13428   -81.1  -26.6  -26.7  -27.9   -5.1    -.4     .0
3   1   2   .12244   -14.9   -3.0   -3.3   -8.6    1.3   -3.1    -.0

3   2   1   .14694  -103.8  -34.8  -33.4  -35.6   -3.8    -.2     .0
3   2   2   .13104   -16.8   -2.9   -3.7  -10.2    1.0   -2.3    -.0

3   3   1   .15339  -107.6  -36.5  -34.6  -36.6   -2.1    -.0     .0
3   3   2   .13720   -18.2   -3.1   -4.0  -11.1     .6   -1.3    -.0

3   4   1   .15265   -74.6  -26.2  -25.9  -22.6    -.7     .0     .0
3   4   2   .14076   -18.8   -3.5   -4.2  -11.2     .3    -.5    -.0

3   5   1   .15089   -52.4  -19.0  -19.9  -13.5    -.1     .0     .0
3   5   2   .14228   -19.1   -3.8   -4.2  -11.1     .0    -.1     .0

T SEG   Z        W   THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
--------------------------------------------------------------------
```

```
 4   1   1   .14094    -94.1  -29.8  -30.7  -33.6   -3.3    -.5     .0
 4   1   2   .12733    -14.8   -3.0   -3.4   -8.4     .9   -3.0     .5

 4   2   1   .15503   -129.0  -41.3  -41.2  -46.5   -2.6    -.2     .1
 4   2   2   .13590    -16.7   -2.9   -3.9  -10.0     .7   -2.2     .6

 4   3   1   .16159   -133.7  -43.2  -42.6  -47.8   -1.8    -.0     .1
 4   3   2   .14204    -18.0   -3.1   -4.2  -10.8     .5   -1.3     .6

 4   4   1   .15956    -88.9  -29.7  -30.3  -28.8   -1.0     .0     .1
 4   4   2   .14560    -18.7   -3.4   -4.3  -10.9     .3    -.5     .7

 4   5   1   .15679    -58.3  -20.4  -21.7  -16.2    -.3     .0     .1
 4   5   2   .14712    -18.9   -3.7   -4.4  -10.8     .0    -.1     .7

 T  SEG  Z       W     THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
--------------------------------------------------------------------------


 5   1   1   .13289    -61.6  -21.5  -19.2  -20.8   -5.3    -.3     .0
 5   1   2   .12391    -13.8   -2.8   -3.7   -7.4    1.4   -2.7     .8

 5   2   1   .14356    -75.6  -27.1  -23.2  -25.2   -4.0    -.2     .0
 5   2   2   .13185    -15.6   -2.7   -4.2   -8.7    1.1   -2.0     .9

 5   3   1   .14947    -77.9  -28.4  -23.8  -25.6   -2.4    -.0     .0
 5   3   2   .13763    -16.8   -2.9   -4.5   -9.4     .7   -1.2    1.0

 5   4   1   .14977    -53.6  -21.0  -17.4  -15.2   -1.0     .0     .0
 5   4   2   .14109    -17.4   -3.2   -4.7   -9.6     .4    -.5    1.0

 5   5   1   .14890    -37.4  -15.8  -13.0   -8.5    -.3     .0     .0
 5   5   2   .14263    -17.7   -3.4   -4.7   -9.5     .1    -.1    1.0

 T  SEG  Z       W     THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
--------------------------------------------------------------------------


 6   1   1   .13999    -43.4  -17.1  -12.1  -14.1   -6.3    -.2     .0
 6   1   2   .13377    -13.9   -2.8   -4.2   -6.9    1.6   -2.5     .0

 6   2   1   .14896    -45.5  -19.5  -12.3  -13.6   -4.8    -.1     .0
 6   2   2   .14165    -15.5   -2.7   -4.7   -8.1    1.3   -1.9     .0

 6   3   1   .15472    -46.3  -20.5  -12.3  -13.4   -2.9    -.0     .0
 6   3   2   .14747    -16.7   -2.8   -5.1   -8.7     .8   -1.2     .0

 6   4   1   .15653    -33.3  -16.5   -9.0   -7.8   -1.3    -.0     .0
 6   4   2   .15106    -17.3   -3.1   -5.3   -8.9     .4    -.5     .0

 6   5   1   .15685    -25.0  -13.7   -6.9   -4.5    -.3     .0     .0
```

```
6   5   2   .15272    -17.6   -3.3   -5.4   -8.9     .1    -.1     .0

T  SEG  Z        W    THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
----------------------------------------------------------------------


7   1   1   .13289    -61.6  -21.5  -19.2  -20.8   -5.3    -.3    -.0
7   1   2   .12391    -13.8   -2.8   -3.7   -7.4    1.4   -2.7    -.8

7   2   1   .14356    -75.6  -27.1  -23.2  -25.2   -4.0    -.2    -.0
7   2   2   .13185    -15.6   -2.7   -4.2   -8.7    1.1   -2.0    -.9

7   3   1   .14947    -77.9  -28.4  -23.8  -25.6   -2.4    -.0    -.0
7   3   2   .13763    -16.8   -2.9   -4.5   -9.4     .7   -1.2   -1.0

7   4   1   .14977    -53.6  -21.0  -17.4  -15.2   -1.0     .0    -.0
7   4   2   .14109    -17.4   -3.2   -4.7   -9.6     .4    -.5   -1.0

7   5   1   .14890    -37.4  -15.8  -13.0   -8.5    -.3     .0    -.0
7   5   2   .14263    -17.7   -3.4   -4.7   -9.5     .1    -.1   -1.0

T  SEG  Z        W    THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
----------------------------------------------------------------------


8   1   1   .14094    -94.1  -29.8  -30.7  -33.6   -3.3    -.5    -.0
8   1   2   .12733    -14.8   -3.0   -3.4   -8.4     .9   -3.0    -.5

8   2   1   .15503   -129.0  -41.3  -41.2  -46.5   -2.6    -.2    -.1
8   2   2   .13590    -16.7   -2.9   -3.9  -10.0     .7   -2.2    -.6

8   3   1   .16159   -133.7  -43.2  -42.6  -47.8   -1.8    -.0    -.1
8   3   2   .14204    -18.0   -3.1   -4.2  -10.8     .5   -1.3    -.6

8   4   1   .15956    -88.9  -29.7  -30.3  -28.8   -1.0     .0    -.1
8   4   2   .14560    -18.7   -3.4   -4.3  -10.9     .3    -.5    -.7

8   5   1   .15679    -58.3  -20.4  -21.7  -16.2    -.3     .0    -.1
8   5   2   .14712    -18.9   -3.7   -4.4  -10.8     .0    -.1    -.7

T  SEG  Z        W    THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
----------------------------------------------------------------------


9   1   1   .13428    -81.1  -26.6  -26.7  -27.9   -5.1    -.4    -.0
9   1   2   .12244    -14.9   -3.0   -3.3   -8.6    1.3   -3.1     .0

9   2   1   .14694   -103.8  -34.8  -33.4  -35.6   -3.8    -.2    -.0
9   2   2   .13104    -16.8   -2.9   -3.7  -10.2    1.0   -2.3     .0

9   3   1   .15339   -107.6  -36.5  -34.6  -36.6   -2.1    -.0    -.0
9   3   2   .13720    -18.2   -3.1   -4.0  -11.1     .6   -1.3     .0
```

```
  9    4    1    .15265    -74.6   -26.2   -25.9   -22.6      -.7      .0     -.0
  9    4    2    .14076    -18.8    -3.5    -4.2   -11.2       .3     -.5      .0

  9    5    1    .15089    -52.4   -19.0   -19.9   -13.5      -.1      .0     -.0
  9    5    2    .14228    -19.1    -3.8    -4.2   -11.1       .0     -.1      .0

   T  SEG   Z         W    THETA    S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
 -------------------------------------------------------------------------------


 10    1    1    .11527    -81.6   -26.0   -27.8   -27.8    -4.4     -.4      .0
 10    1    2    .10329    -13.8    -2.8    -2.6    -8.4     1.1    -3.0      .3

 10    2    1    .12751   -106.0   -34.7   -35.1   -36.3    -3.2     -.2      .0
 10    2    2    .11129    -15.7    -2.7    -3.0   -10.0      .9    -2.2      .4

 10    3    1    .13353   -110.2   -36.3   -36.5   -37.4    -1.6     -.1      .0
 10    3    2    .11697    -16.9    -2.9    -3.3   -10.8      .5    -1.2      .4

 10    4    1    .13241    -76.8   -25.8   -27.7   -23.3     -.4      .0      .0
 10    4    2    .12020    -17.6    -3.3    -3.3   -11.0      .2     -.5      .4

 10    5    1    .13041    -54.3   -18.5   -21.7   -14.1     -.0      .0      .0
 10    5    2    .12154    -17.8    -3.6    -3.4   -10.8      .0     -.0      .5

   T  SEG   Z         W    THETA    S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
 -------------------------------------------------------------------------------


 11    1    1    .11161    -96.2   -29.2   -32.5   -34.5    -2.0     -.5      .1
 11    1    2    .09766    -12.6    -2.5    -2.3    -7.7      .5    -2.7     1.3

 11    2    1    .12501   -135.5   -41.6   -44.5   -49.3    -1.6     -.3      .1
 11    2    2    .10504    -14.4    -2.4    -2.7    -9.3      .4    -2.0     1.5

 11    3    1    .13074   -140.9   -43.5   -46.3   -51.1    -1.0     -.0      .2
 11    3    2    .11024    -15.5    -2.6    -2.9   -10.0      .3    -1.1     1.6

 11    4    1    .12779    -94.0   -29.3   -33.5   -31.2     -.5      .0      .2
 11    4    2    .11314    -16.1    -3.0    -3.0   -10.1      .2     -.4     1.7

 11    5    1    .12447    -61.8   -19.4   -24.4   -18.0     -.1      .0      .2
 11    5    2    .11433    -16.2    -3.3    -3.0   -10.0      .0     -.0     1.7

   T  SEG   Z         W    THETA    S-XX    S-YY    S-ZZ    S-XY    S-XZ    S-YZ
 -------------------------------------------------------------------------------


 12    1    1    .09361    -57.3   -18.6   -18.7   -19.9    -3.3     -.3      .2
 12    1    2    .08522    -10.1    -2.0    -2.3    -5.8      .8    -2.1     2.0

 12    2    1    .10248    -74.6   -24.8   -23.9   -26.0    -2.5     -.2      .2
```

```
12   2   2   .09108   -11.4   -2.0   -2.6   -6.9     .6   -1.5    2.4

12   3   1   .10688   -77.3  -25.9  -24.7  -26.7   -1.4    -.0     .2
12   3   2   .09527   -12.3   -2.1   -2.8   -7.5     .4    -.9    2.6

12   4   1   .10615   -52.8  -18.3  -18.2  -16.3    -.5     .0     .3
12   4   2   .09769   -12.8   -2.3   -2.9   -7.6     .2    -.3    2.7

12   5   1   .10477   -36.3  -13.1  -13.7   -9.5    -.1     .0     .2
12   5   2   .09872   -12.9   -2.6   -2.9   -7.5     .0    -.0    2.7

 T  SEG  Z       W    THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
----------------------------------------------------------------------

13   1   1   .06999   -21.7   -8.6   -6.1   -7.1   -3.1    -.1     .1
13   1   2   .06688    -6.9   -1.4   -2.1   -3.4     .8   -1.3    2.0

13   2   1   .07448   -22.7   -9.7   -6.2   -6.8   -2.4    -.0     .2
13   2   2   .07082    -7.8   -1.4   -2.4   -4.0     .6   -1.0    2.3

13   3   1   .07736   -23.1  -10.2   -6.2   -6.7   -1.4    -.0     .2
13   3   2   .07373    -8.3   -1.4   -2.6   -4.3     .4    -.6    2.5

13   4   1   .07826   -16.7   -8.3   -4.5   -3.9    -.7     .0     .2
13   4   2   .07553    -8.7   -1.6   -2.7   -4.4     .2    -.3    2.6

13   5   1   .07843   -12.5   -6.9   -3.4   -2.2    -.2     .0     .2
13   5   2   .07636    -8.8   -1.7   -2.7   -4.4     .0    -.0    2.6

 T  SEG  Z       W    THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
----------------------------------------------------------------------

14   1   1   .03928    -4.3   -2.8    -.5    -.9   -2.0    -.0     .1
14   1   2   .03868    -3.7    -.8   -1.4   -1.6     .5    -.6    1.3

14   2   1   .04109    -1.0   -2.4     .6     .7   -1.6    -.0     .1
14   2   2   .04077    -4.2    -.7   -1.6   -1.8     .4    -.5    1.5

14   3   1   .04259     -.6   -2.6     .9    1.0   -1.0    -.0     .2
14   3   2   .04236    -4.5    -.8   -1.7   -2.0     .3    -.3    1.6

14   4   1   .04362     -.8   -2.7     .8    1.0    -.5     .0     .2
14   4   2   .04340    -4.6    -.8   -1.8   -2.0     .2    -.2    1.7

14   5   1   .04413    -1.1   -2.7     .7     .9    -.1     .0     .2
14   5   2   .04391    -4.7    -.8   -1.8   -2.1     .0    -.0    1.7

 T  SEG  Z       W    THETA   S-XX   S-YY   S-ZZ   S-XY   S-XZ   S-YZ
----------------------------------------------------------------------
```

```
15    1    1    .02932        2.1      -.6      1.9       .9     -1.3       .0       .0
15    1    2    .02967       -2.2      -.4     -1.1      -.7       .3      -.3       .8

15    2    1    .03002        6.5       .3      3.3      2.8     -1.1       .0       .0
15    2    2    .03086       -2.4      -.4     -1.2      -.7       .3      -.2       .9

15    3    1    .03086        7.2       .3      3.7      3.2      -.8       .0       .0
15    3    2    .03180       -2.5      -.4     -1.3      -.8       .2      -.2      1.0

15    4    1    .03177        5.1      -.4      3.2      2.4      -.5       .0       .0
15    4    2    .03246       -2.6      -.4     -1.4      -.8       .1      -.1      1.0

15    5    1    .03231        3.6      -.9      2.7      1.8      -.1       .0       .0
15    5    2    .03280       -2.7      -.4     -1.4      -.8       .0      -.0      1.0

 T  SEG    Z        W        THETA     S-XX     S-YY     S-ZZ     S-XY     S-XZ     S-YZ
-----------------------------------------------------------------------------------------


16    1    1    .01901         .5      -.5      1.1      -.0      -.7       .0      -.0
16    1    2    .01914       -1.1      -.2      -.6      -.2       .2      -.0       .4

16    2    1    .01943        2.2      -.2      1.7       .6      -.6       .0       .0
16    2    2    .01975       -1.2      -.2      -.7      -.2       .1      -.0       .4

16    3    1    .01985        2.6      -.2      1.9       .8      -.5       .0      -.0
16    3    2    .02023       -1.2      -.2      -.8      -.2       .1      -.0       .4

16    4    1    .02025        2.2      -.4      1.9       .7      -.3       .0      -.0
16    4    2    .02057       -1.3      -.2      -.8      -.3       .0      -.0       .5

16    5    1    .02048        1.9      -.5      1.9       .6      -.1       .0      -.0
16    5    2    .02074       -1.3      -.2      -.8      -.3       .0      -.0       .5
```

3.0 User's Manual for the GEOPLOT Computer Program

The GEOPLOT post-processing graphics package was developed by Clifton Associates Ltd. and the University of Saskatchewan to facilitate the use of the GEOTRACK computer program for stress analysis. The GEOPLOT post-processing graphics package contains elements of copyrighted software for which D.G. Fredlund of GEO-SLOPE Programming Ltd. has distribution rights. Distribution of the GEOPLOT graphics package is limited to the project research group: 1) Canadian National Railways, 2) Canadian Pacific Railways, and 3) the Transportation Development Center.

3.1 Introduction to the GEOPLOT Graphics Program

The GEOPLOT post-processing computer program was developed to facilitate the use of the GEOTRACK computer program for stress analysis. GEOPLOT meets the need for graphic representation of the lengthy output file derived from the GEOTRACK computer program.

GEOPLOT is an interactive computer program which reads the GEOTRACK output file of stresses and displacements and presents the user with various menus for plotting the available GEOTRACK output. Although the GEOTRACK output is available in only British Imperial units, GEOPLOT may plot the output in either British Imperial units or SI units.

GEOPLOT features both manual and automatic scaling functions. The incorporation of these features has the advantage of significantly increasing user-friendliness. However, the scaling notation for the generated plot is consequently limited to scientific notation format.

The GEOPLOT graphics package prepares two-dimensional plots of the three-dimensional state of stresses and displacements beneath the track structure. Plots can be prepared for directions parallel to the track (i.e., by tie segment number) or for directions perpendicular to the track (i.e., by tie number). Once the plot file has been prepared by the GEOPLOT program, the graph may be viewed on the screen or plotted on a printer.

3.2 Description of the GEOPLOT Graphics Package

Figure 3.1 presents a simplified general algorithm showing the logic of the GEOPLOT computer program. The user is requested to choose either British Imperial or SI (i.e., metric) units. If additional depth information is located within the GEOTRACK output file, the user is informed and given the option to plot the additional depth information.

The GEOPLOT graphics package reads in the control data from the GEOTRACK output file to determine which plotting options are available to the user. The user is prompted by screen menus for the desired type of plot. If the user errs in asking for information that is not available, GEOPLOT informs the user that the information is unavailable and asks the user for another request. This serves to make the GEOPLOT computer program user-friendly.

There are 40 different plots available from a complete GEOTRACK output file. Within section 2.3 of the GEOTRACK user's manual, Data Entry Type 13 describes the three optional stress calculations (i.e., for incremental stress, for principal stress and for equivalent triaxial stress). If ITSTD = 1 in Data Entry Type 13, there are available 8 standard soil output plots plus an additional 8 plots of

1) Display name of program.
2) Input drive and directory, name of GEOTRACK output file and name for '.PLT' file to be created.
3) Choose between British Imperial and SI units.
4) If additional depth information available, determine if user wishes to plot additional depth information.
5) Display plotting menu for user to choose graph type.
6) If graph type is represented by sub-menu, display sub-menu for user to choose option.
7) Determine if plot is to be drawn by tie no. or segment no.
8) Read appropriate data from GEOTRACK output file.
9) Perform calculations for automatic scaling.
10) Display automatic scale and ask user for choice of automatic or manual scaling.
11) If manual scaling desired, prompt user for maximum and minimum scale values. Check if plotting data falls within range. If not, prompt user for scale values.
12) Create plotting file. Display message to screen.
13) Ask if user wishes to run program again. If yes, start over at item 1). If not, exit from the program.

Fig. 3.1 General Algorithm for GEOPLOT Graphics Program

soil vertical displacement and incremental stresses. If ITPRIN = 1 in Data Entry Type 13, an additional 15 plots for the principal stress computations can be created by the GEOPLOT graphics package. Nine more plots are available from the GEOPLOT graphics package if ITRIAX = 1 in Data Entry Type 13 for the GEOTRACK output file. The total available plots equals 8 + 8 + 15 + 9 or 40. A description of the available plots is presented in Table 3.1.

The GEOPLOT graphics package prepares two-dimensional plots of the three-dimensional state of stresses and displacements beneath the track structure for directions parallel to the track (i.e., by tie segment number) or for directions perpendicular to the track (i.e., by tie number). Figures 3.2 and 3.3 illustrate the directions parallel to the track and perpendicular to the track, respectively. The user is requested to choose plotting by either tie segment number or by tie number.

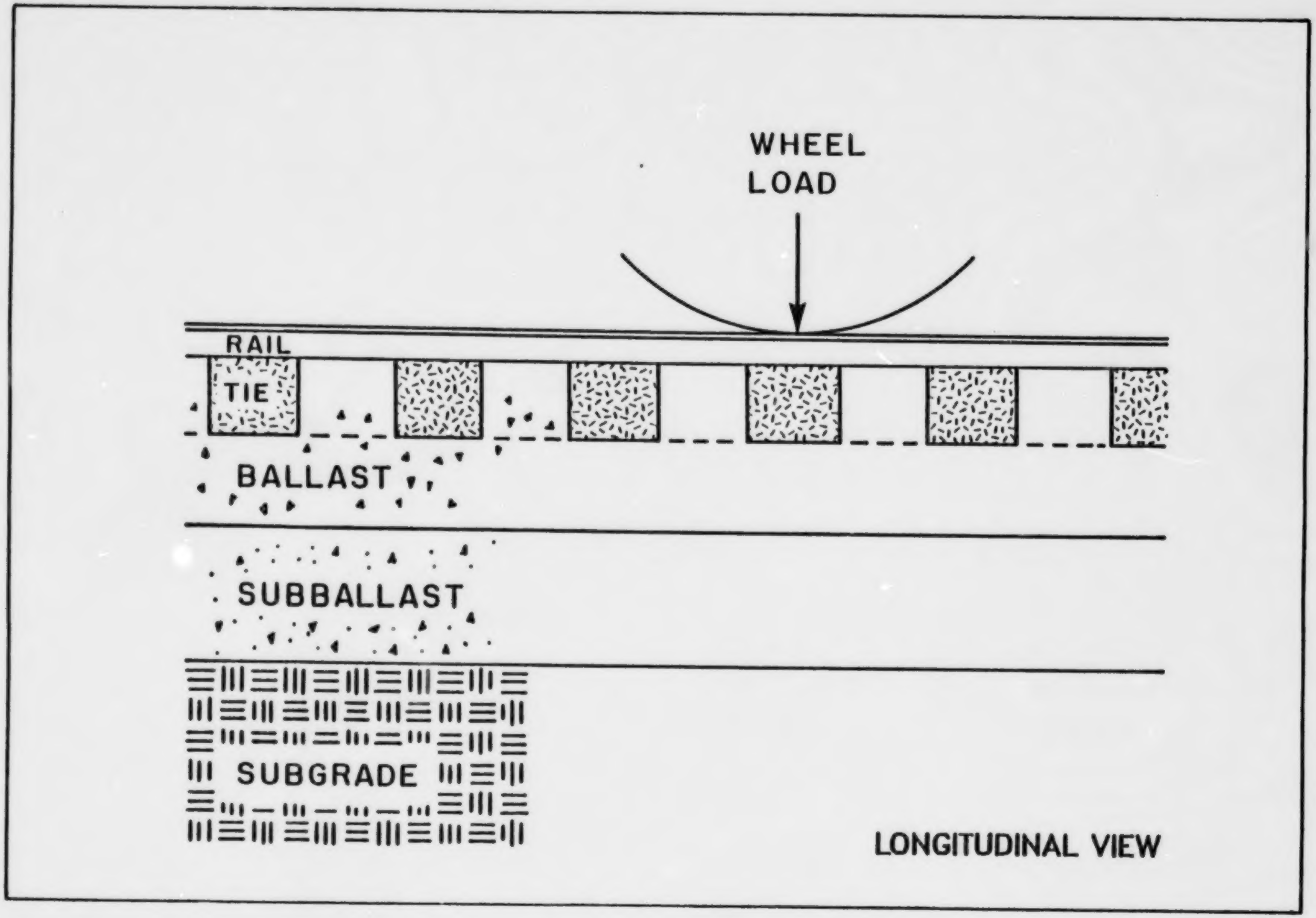

WHEEL
LOAD
RAIL
TIE
BALLAST
SUBBALLAST
SUBGRADE
LONGITUDINAL VIEW

Fig. 3.2 Longitudinal view of the track system showing the geometry parallel to the track

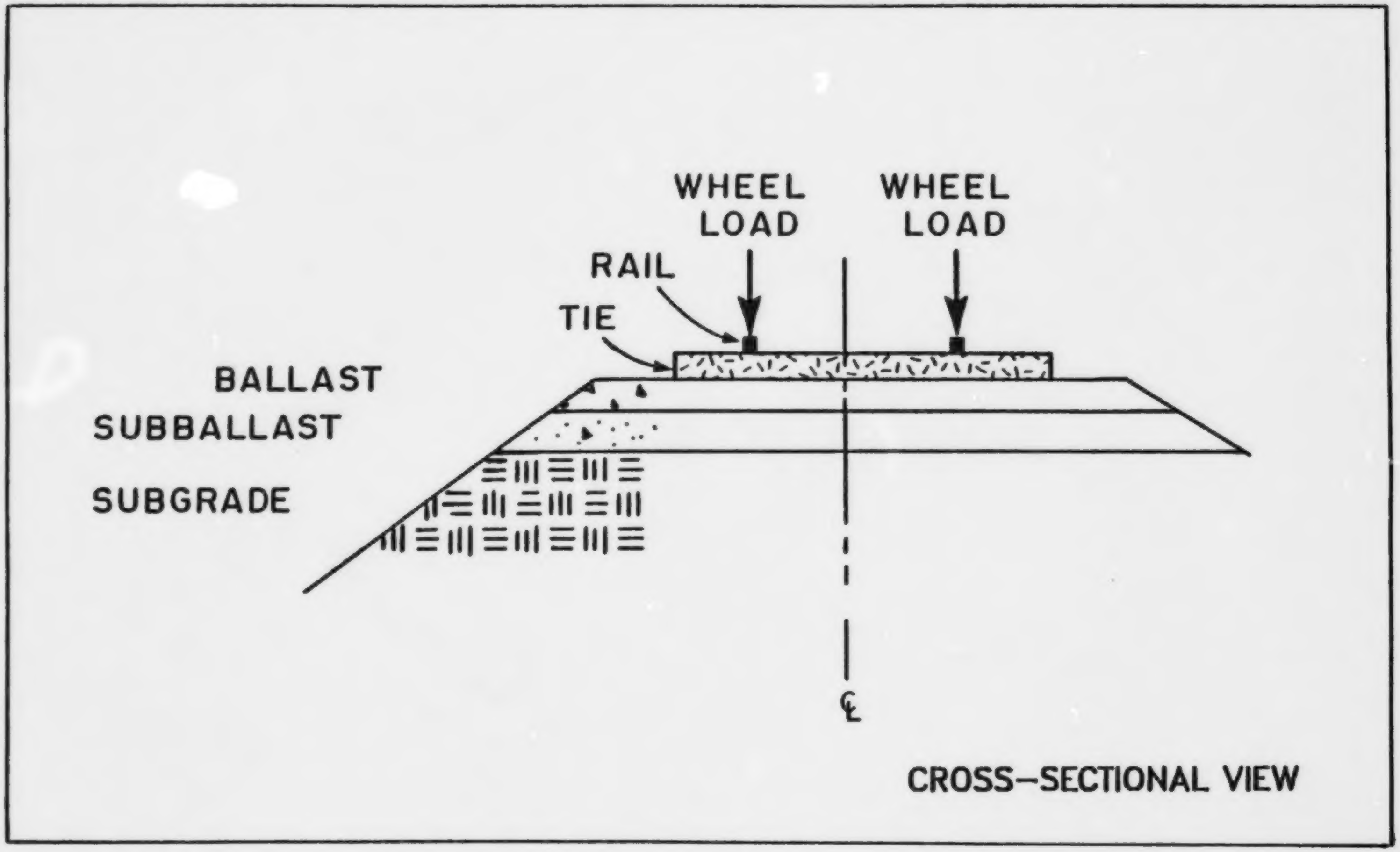

WHEEL LOAD
WHEEL LOAD
RAIL
TIE
BALLAST
SUBBALLAST
SUBGRADE
℄
CROSS-SECTIONAL VIEW

Fig. 3.3 Cross-sectional view of the track system showing the geometry perpendicular to the track

Once the GEOPLOT program has established the type of plot that the user desires, the GEOTRACK output file is searched to locate the appropriate information. Unit conversions are performed on the data for SI plots and the layout of the plot is established and written to a plot file.

The resulting scale for automatic scaling is displayed on the screen and the user is given the option to accept the automatic scale or to input a manual scale which will plot the limits of the data to be illustrated. GEOPLOT will not allow the user to input a scale which would effectively eliminate some of the data.

Following the choice of an appropriate scale, the plotting file is created for viewing or plotting. Alternatively, the user may wish to start over and create another plotting file. Once a plotting file has been created, the plot is viewed by typing "VIEW filename.PLT" or plotted by typing "PLOT filename.PLT" at the DOS prompt.

3.3 Screen Displays and User Response

The following pages present the screen displays for the GEOPLOT computer program and the user responses for the various desired plots.

The GEOPLOT computer program is executed by typing 'GEOPLOT' at the cursor prompt provided the GEOPLOT program is available in the prompt directory. For example, if the GEOPLOT program has been loaded onto a hard disk into the 'C:\MANUALS\' directory, the command to begin program execution would be typed at the 'C:\MANUALS\>' prompt.

The first screen display which appears is illustrated on the next page. The GEOPLOT program asks the user to input the drive and directory in which the input and output files will be manipulated.

Next, the input data file name is requested and the output data file name is requested. GEOPLOT determines if the user wishes to use SI (i.e., metric) or British Imperial units for the plot. If the results of other depths are available in the input data file, the GEOPLOT program informs the user and asks if the user desires to plot the results for the other depths.

The following page shows all available plotting options. If any particular option is unavailable within the input data file, the user will be informed and asked for another request. Within each of options 9, 10, and 11, several additional options are available (Refer to Table 3.1). Next, the screen display presented on the next page shows the 8 additional options available for option 9, the vertical displacements and incremental stresses. The file E1035T36.OGT did not contain the stresses required to plot options 10 and 11. Next GEOPLOT determines if the user wishes to plot by tie number or by segment number and the corresponding number of the tie or segment. (Refer to Figures 3.2 and 3.3 for definitions of the two directions.)

The user is then requested to wait for a few moments while the appropriate data is located within the data file and read. The user is given the option of using the default maximum and minimum values or setting other convenient limits. When the plotting file has been created, the user is informed and asked for the next assignment.

The plot can be viewed on the screen using the command 'VIEW filename.PLT'. Figure 3.4 illustrates a typical screen display upon

```
                 GGGGGGG   EEEEEEEE   000000   PPPPPPP   LL        000000   TTTTTTTT
                 GGGGGGGG  EEEEEEEE  00000000  PPPPPPPP  LL       00000000  TTTTTTTT
                 GG    GG  EE        OO    OO  PP    PP  LL       OO    OO     TT
                 GG        EE        OO    OO  PP    PP  LL       OO    OO     TT
                 GG  GGGG  EEEEEEEE  OO    OO  PPPPPPPP  LL       OO    OO     TT
                 GG  GGGG  EE        OO    OO  PPPPPPPP  LL       OO    OO     TT
                 GG    GG  EE        OO    OO  PP        LL       OO    OO     TT
                 GGGGGGGG  EEEEEEEE  00000000  PP        LLLLLLLL 00000000     TT
                 GGGGGGGG  EEEEEEEE   000000   PP        LLLLLLLL  000000      TT

                     GEOPLOT  is a computer program which sets up a file for
                     plotting and viewing output data computed with GEOTRACK.

                       Clifton Associates Ltd. & University of Saskatchewan
                                      Saskatoon, Canada.
                                         ( Feb. 1988 )

--------------------------------------------------------------------------------
DRIVE & DIRECTORY for Input/Output files ?
( e.g., C:, C:\WORK\, or BLANK for current DIR )...........: C:\MANUALS\
INPUT  DATA FILE name ( Do not include .OGT )..............: E1035T36
OUTPUT DATA FILE name ( Do not include .PLT )..............: PLOT1

          ---- PLOTTING UNIT ----

ENTER  1 - Metric  unit will be plotted
       2 - British unit will be plotted....................: 1


Data file contains results of other depths,
do you want to plot results of other depths now (Y/N) ?....: Y
```

```
                ----  PLOTTING MENU ----

      ENTER  0 - EXIT FROM GEOPLOT
             1 - RAIL DEFLECTION
             2 - RAIL-SEAT REACTION
             3 - TIE DEFLECTION
             4 - TIE CENTRE BENDING MOMENT
             5 - TIE RAIL-SEAT BENDING MOMENT
             6 - RAIL BENDING MOMENT
             7 - TIE-SOIL REACTIONS
             8 - TIE SEGMENT DEFLECTION
             9 - SOIL VERTICAL DISPLACMENT & INCREMENTAL STRESSES
            10 - SOIL INCREMENTAL PRINCIPAL STRESSES
            11 - SOIL EQUIVALENT TRIAXIAL STRESSES...............: 9

                ----  OPTIONS  ----

      ENTER  1 - W,      VERTICAL DISPLACEMENT
             2 - THETA
             3 - S-XX,  DIRECTION PARALLEL TO TIE
             4 - S-YY,  DIRECTION PARALLEL TO RAIL
             5 - S-ZZ,  VERTICAL DIRECTION
             6 - S-XY
             7 - S-XZ
             8 - S-YZ ..........................................: 5




                ----  OPTIONS  ----

      ENTER  1 - Plot by TIE number
             2 - Plot by SEGMENT number.........................: 1

      ENTER desired TIE number (1 to 17)........................: 1
```

```
** Reading data, please wait **

Maximum data value =   .35241E+03
Minimum data value =   .53103E+02

These values will be used in plot by default.

Do you want to set other Max. & Min. limits (Y/N) ?........: Y

** Reading data, please wait **

Maximum data value =   .35241E+03
Minimum data value =   .53103E+02

These values will be used in plot by default.

Do you want to set other Max. & Min. limits (Y/N) ?........: Y

ENTER desired maximum ( E or F format)....: 400
ENTER desired minimum ( E or F format)....: 0


========= Computation completed =========

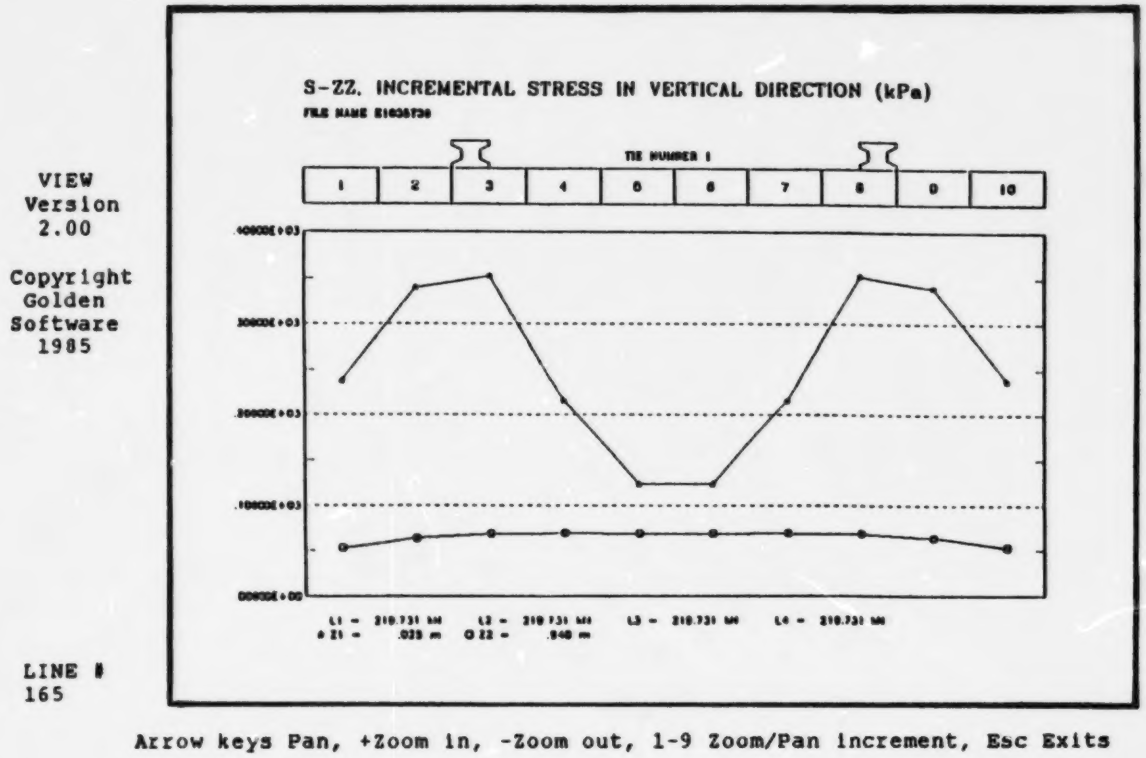
The following plotting file is generated :

          C:\MANUALS\PLOT1.PLT

To view plot on screen, type  VIEW (file name)
To get plot on printer, type  PLOT (file name) /B


Do you want to do MORE plotting (Y/N) ?...................: N


C:\MANUALS>VIEW PLOT1.PLT
```


S-ZZ. INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)
FILE NAME
TIE NUMBER I
1
2
3
4
5
6
7
8
9
10
.40000E+03
.30000E+03
.20000E+03
.10000E+03
.00000E+00
L1 = 210.731 kN
L2 = 210.731 kN
L3 = 210.731 kN
L4 = 210.731 kN
● Z1 = .025 m
○ Z2 = .940 m

VIEW
Version
2.00

Copyright
Golden
Software
1985

LINE #
165

Arrow keys Pan, +Zoom in, -Zoom out, 1-9 Zoom/Pan increment, Esc Exits

Figure 3.4 Using VIEW to View a GEOPLOT File

asking to view the file. The '+' and '-' and arrow keys can then be used to view any portion of the plot in greater detail. The viewing process is exited by pressing the 'ESC' key, using the arrow keys to sit on the 'QUIT' option and hitting return. The plot can be plotted on the printer by typing 'PLOT filename.PLT/B' at the cursor prompt. An optimized file is created (i.e., a file of printer commands) and the plot is printed onto the printer. This usually takes a few minutes.

If Option 10 had been chosen, the 15 additional options which could be plotted are shown on the next page. If Option 11 had been chosen, there are an additional 9 plots available as shown on page 95.

```
              ----  PLOTTING MENU ----

      ENTER  0 - EXIT FROM GEOPLOT
             1 - RAIL DEFLECTION
             2 - RAIL-SEAT REACTION
             3 - TIE DEFLECTION
             4 - TIE CENTRE BENDING MOMENT
             5 - TIE RAIL-SEAT BENDING MOMENT
             6 - RAIL BENDING MOMENT
             7 - TIE-SOIL REACTIONS
             8 - TIE SEGMENT DEFLECTION
             9 - SOIL VERTICAL DISPLACMENT & INCREMENTAL STRESSES
            10 - SOIL INCREMENTAL PRINCIPAL STRESSES
            11 - SOIL EQUIVALENT TRIAXIAL STRESSES...............: 10

              ----  OPTIONS  ----

      ENTER  1 - W,     VERTICAL DISPLACEMENT
             2 - SIG1,  MAXIMUM PRINCIPAL STRESS
             3 - A1X,   DIRECTIONAL COSINE FOR SIG1 IN X DIRECTION
             4 - A1Y,   DIRECTIONAL COSINE FOR SIG1 IN Y DIRECTION
             5 - A1Z,   DIRECTIONAL COSINE FOR SIG1 IN Z DIRECTION
             6 - SIG2,  INTERMEDIATE PRINCIPAL STRESS
             7 - A2X,   DIRECTIONAL COSINE FOR SIG2 IN X DIRECTION
             8 - A2Y,   DIRECTIONAL COSINE FOR SIG2 IN Y DIRECTION
             9 - A2Z,   DIRECTIONAL COSINE FOR SIG2 IN Z DIRECTION
            10 - SIG3,  MINIMUM PRINCIPAL STRESS
            11 - A3X,   DIRECTIONAL COSINE FOR SIG3 IN X DIRECTION
            12 - A3Y,   DIRECTIONAL COSINE FOR SIG3 IN Y DIRECTION
            13 - A3Z,   DIRECTIONAL COSINE FOR SIG3 IN Z DIRECTION
            14 - BULK,  BULK STRESS = SIG1+SIG2+SIG3
            15 - DEV,   DEVIATOR STRESS = SIG1-SIG3 .............:
```

ADDITIONAL PLOTTING OPTIONS WITHIN OPTION 10

```
              ----  PLOTTING MENU ----

      ENTER  0 - EXIT FROM GEOPLOT
             1 - RAIL DEFLECTION
             2 - RAIL-SEAT REACTION
             3 - TIE DEFLECTION
             4 - TIE CENTRE BENDING MOMENT
             5 - TIE RAIL-SEAT BENDING MOMENT
             6 - RAIL BENDING MOMENT
             7 - TIE-SOIL REACTIONS
             8 - TIE SEGMENT DEFLECTION
             9 - SOIL VERTICAL DISPLACMENT & INCREMENTAL STRESSES
            10 - SOIL INCREMENTAL PRINCIPAL STRESSES
            11 - SOIL EQUIVALENT TRIAXIAL STRESSES...............: 11

              ----  OPTIONS  ----

      ENTER  1 - GEOSTATIC VERTICAL STRESS
             2 - INITIAL P
             3 - INITIAL Q
             4 - SOCT,  OCTAHEDRAL NORMAL STRESS
             5 - TOCT,  OCTAHEDRAL SHEAR STRESS
             6 - SIG 1
             7 - SIG 3
             8 - MAXIMUM P
             9 - MAXIMUM Q ....................................: 1

              ----  OPTIONS  ----

      ENTER  1 - Plot by TIE number
             2 - Plot by SEGMENT number.........................:
```

ADDITIONAL PLOTTING OPTIONS
WITHIN OPTION 11

Table 3.1 List of Available GEOPLOT Plots

1) **Rail Deflection:** the deflection of either rail for the distance of all the ties modelled by the GEOTRACK computer program,
2) **Rail-Seat Reaction:** the concentrated force between the rail and each tie for all the ties modelled,
3) **Tie Deflection:** the deflection of the ties beneath the rail,
4) **Tie Center Bending Moment:** the bending moment exhibited at the center of each tie for all the ties modelled by the GEOTRACK computer program,
5) **Tie Rail-Seat Bending Moment:** the bending moment exhibited at the location of the rail on each tie for all ties modelled,
6) **Rail Bending Moment:** the bending moment within the rail at each tie location,
7) **Tie-Soil Reactions:** the concentrated force between the tie and the soil, either by tie no. or by segment no.,
8) **Tie Segment Deflection:** the deflection of any tie segment, either by tie No. or by segment No.,

Soil Vertical Displacement and Incremental Stresses: the incremental displacements and stresses due to the applied loading, that is any one of the following plots, either by tie No. or by segment No.:

9) **W, Vertical Displacement:** the incremental vertical displacement due to loading for the depth locations calculated,
10) **Theta:** the angle defining the direction ofthe incremental stresses,
11) **S-XX:** the incremental horizontal stress in a direction parallel

to the tie,

12) S-YY: the incremental horizontal stress in a direction parallel to the rail,

13) S-ZZ: the incremental vertical stress caused by the applied loading configuration,

14) S-XY: the incremental shear stress in the X-Y plane,

15) S-XZ: the incremental shear stress in the X-Z plane,

16) S-YZ: the incremental shear stress in the Y-Z plane,

Soil Incremental Principal Stresses: by the Mohr circle method of illustrating stress states, principal stresses due to the applied loading, that is any one of the following, either by tie No. or by segment No.:

17) W, Vertical Displacement: the incremental vertical displacement due to loading for the depth locations calculated,

18) SIG1: the maximum principal stress,

19) A1X: the directional cosine for the maximum principal stress in the x-direction,

20) A1Y: the directional cosine for the maximum principal stress in the y-direction,

21) A1Z: the directional cosine for the maximum principal stress in the z-direction,

22) SIG2: the intermediate principal stress,

23) A2X: the directional cosine for the intermediate principal stress in the x-direction,

24) A2Y: the directional cosine for the intermediate principal stress in the y-direction,

25) A2Z: the directional cosine for the intermediate principal stress

in the z-direction,

26) SIG3: the minimum principal stress,

27) A3X: the directional cosine for the minimum principal stress in the x-direction,

28) A3Y: the directional cosine for the minimum principal stress in the y-direction,

29) A3Z: the directional cosine for the minimum principal stress in the z-direction,

30) Bulk Stress: the sum of the three principal stresses (i.e., the sum of the maximum, intermediate, and minimum principal stresses),

31) Deviator Stress: the difference between the maximum principal stress and the minimum principal stress,

Soil Equivalent Triaxial Stresses: the theoretical equivalent triaxial stresses for the applied loading configuration, that is any one of the following, either by tie No. or by segment No.:

32) Geostatic Vertical Stress: the stress caused by weight of the rails, ties and depth of overburden for the calculated depths,

33) Initial p: the value of p (See Equation 1) before the application of load by the stress path method,

34) Initial q: the value of q (See Equation 1) before the application of load by the stress path method,

35) Octahedral Normal Stress: the three-dimensional octahedral normal stress, as described in Appendix A,

36) Octahedral Shear Stress: the three-dimensional octahedral shear stress, as described in Appendix A,

37) SIG1: the theoretical maximum principal stress upon elimination

of the intermediate stress,

38) SIG3: the theoretical minimum principal stress upon elimination of the intermediate stress,

39) Maximum p: the maximum value of p by the stress path method, and

40) Maximum q: the maximum value of q by the stress path method.

3.4 Typical Output

Typical output from the GEOPLOT computer program is presented in Figures 3.5 to 3.23. Figure 3.5 was generated by the example screen displays and responses shown in the previous section for tie number 1. Figure 3.6 was generated by requesting that the stress distribution plot beneath the track structure be created by segment number (instead of by tie number) for segment number 3. The output illustrated in Figures 3.5 and 3.6 was used for averaging the ballast and subgrade surface stresses for the bearing capacity design approach to railway subgrades.

Whereas Figures 3.5 and 3.6 represent the results for the alternate depths vertical stress (i.e., option 9 from the first menu and option 5 from the second menu), Figure 3.7 represents the horizontal stress parallel to the rail (i.e., option 4 from the second option menu). Figure 3.8 shows the soil vertical displacement which was generated from option 1 of the second menu. Five additional plots could be created from the options within option 9, the soil vertical displacement and incremental stresses.

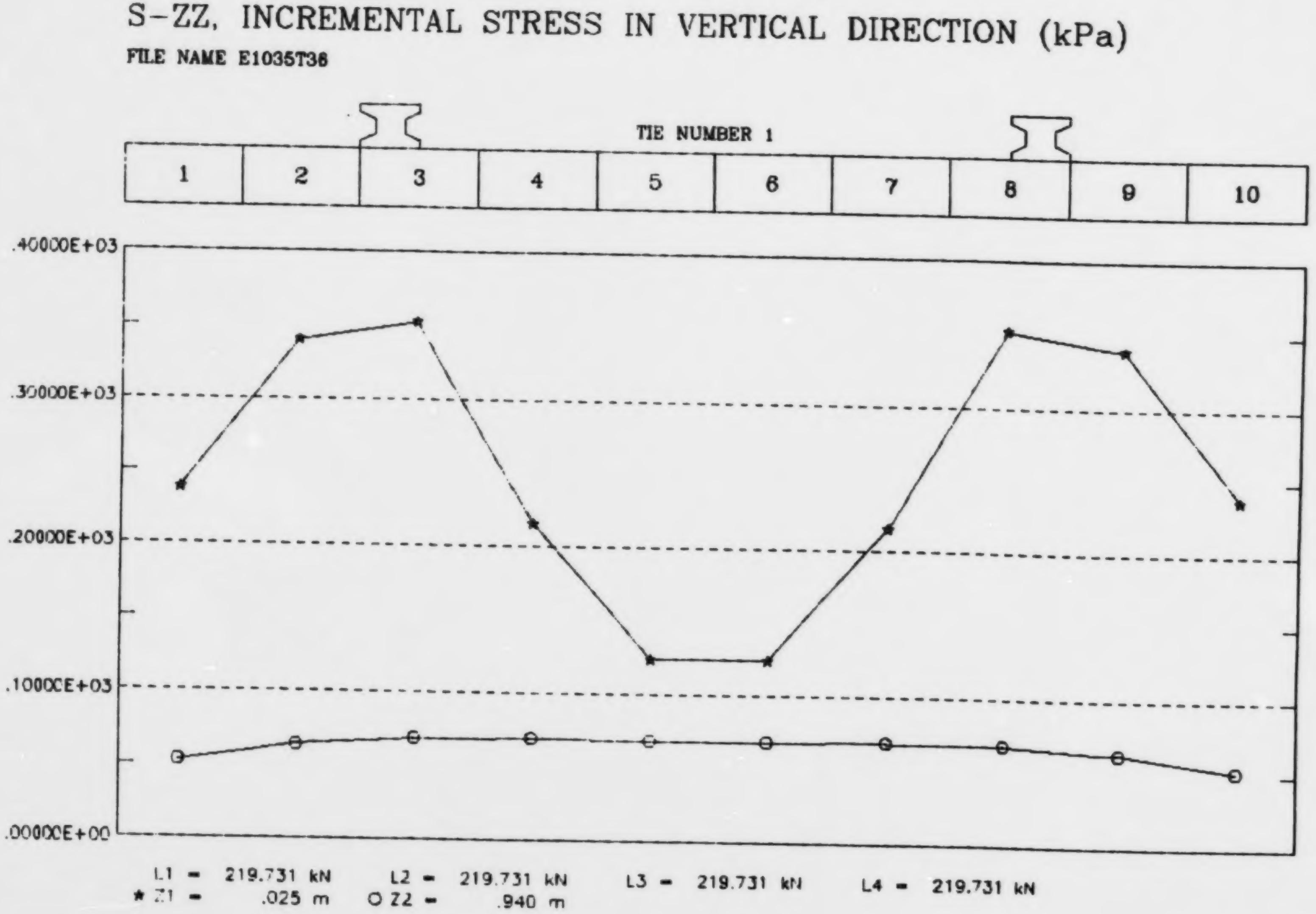


Figure 3.5 GEOPLOT Vertical Stress Perpendicular to the Track

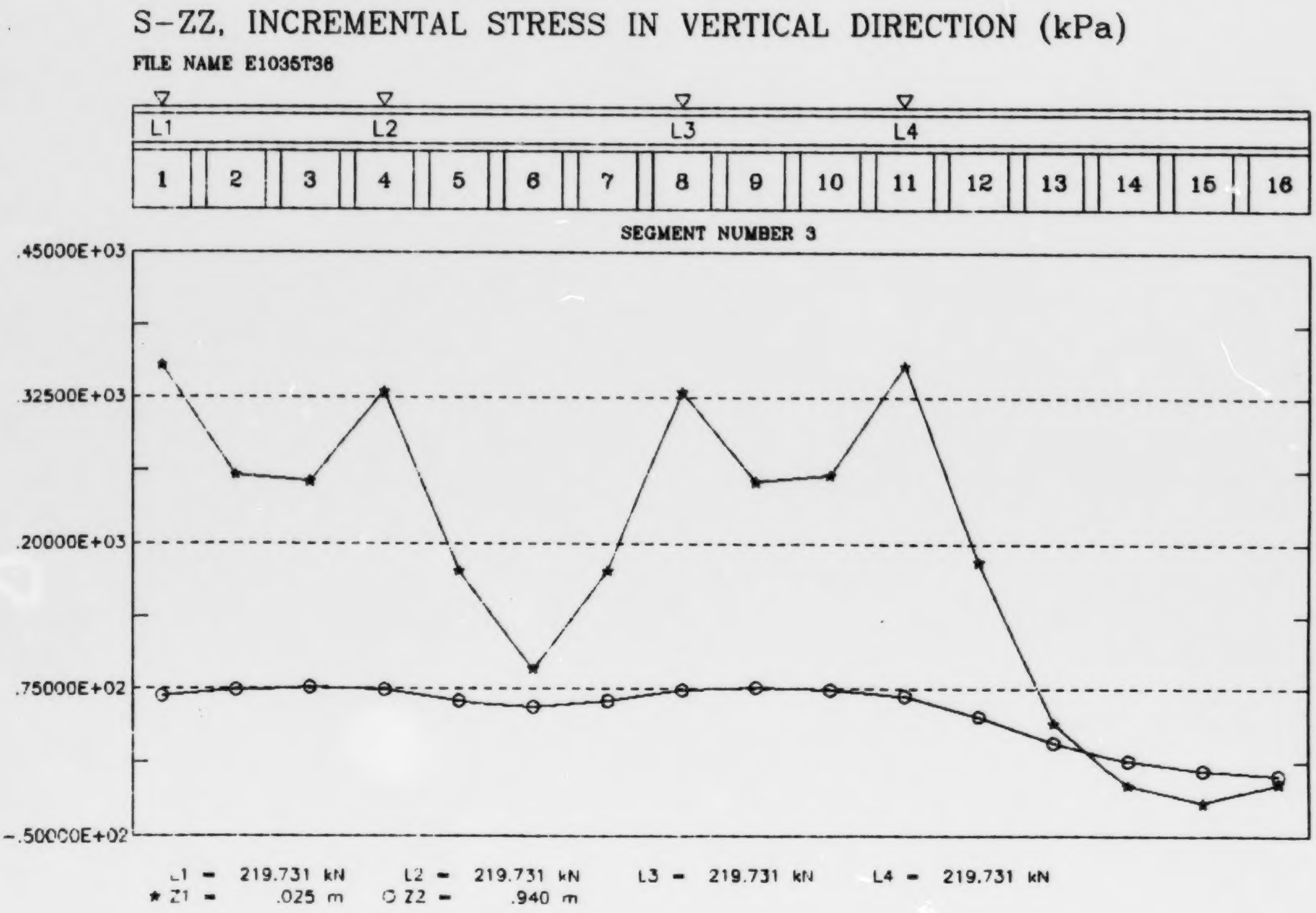


Figure 3.6 GEOPLOT Vertical Stress Parallel to the Track

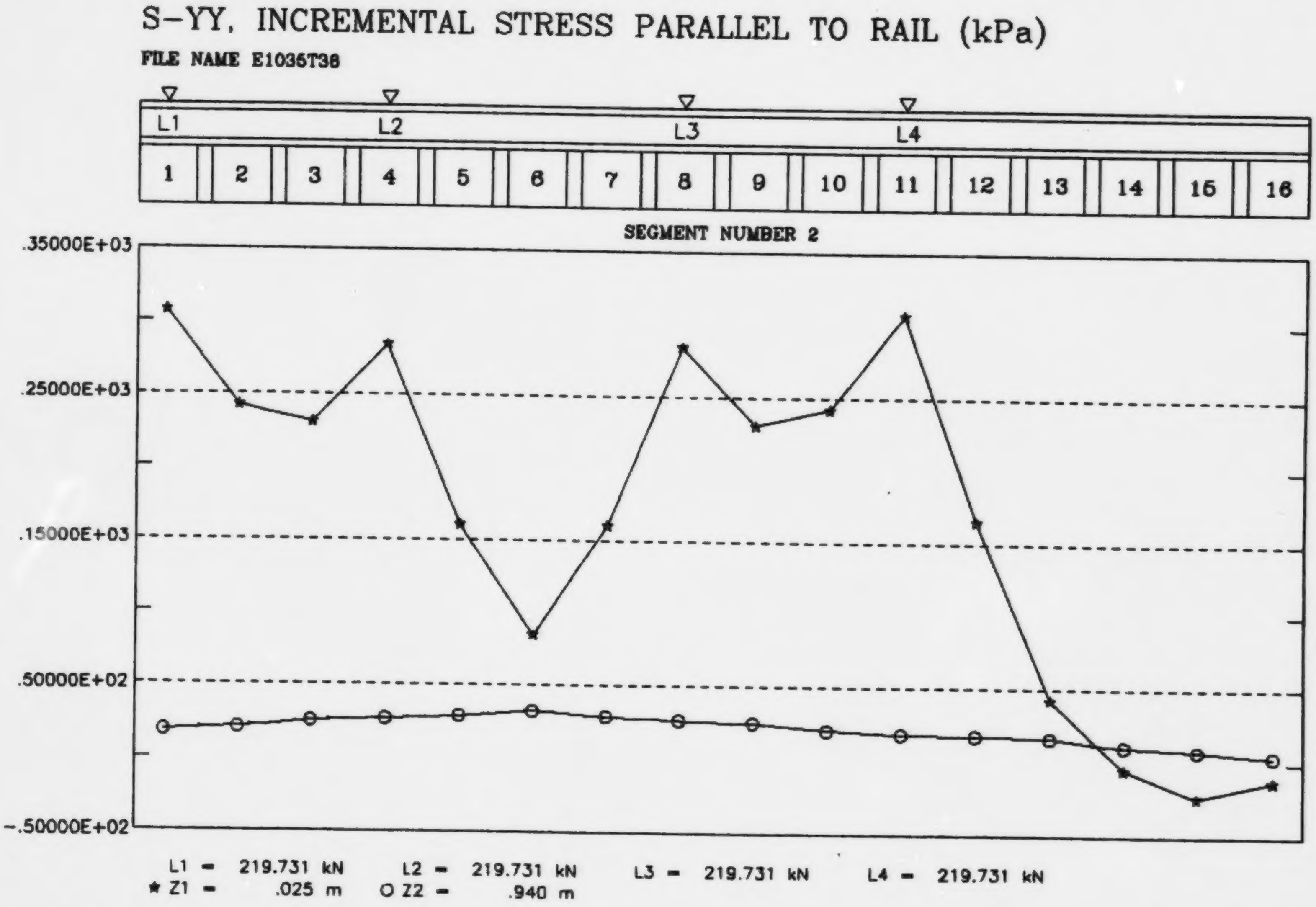


Figure 3.7 GEOPLOT Horizontal Stress in the Y-direction Parallel to the Track

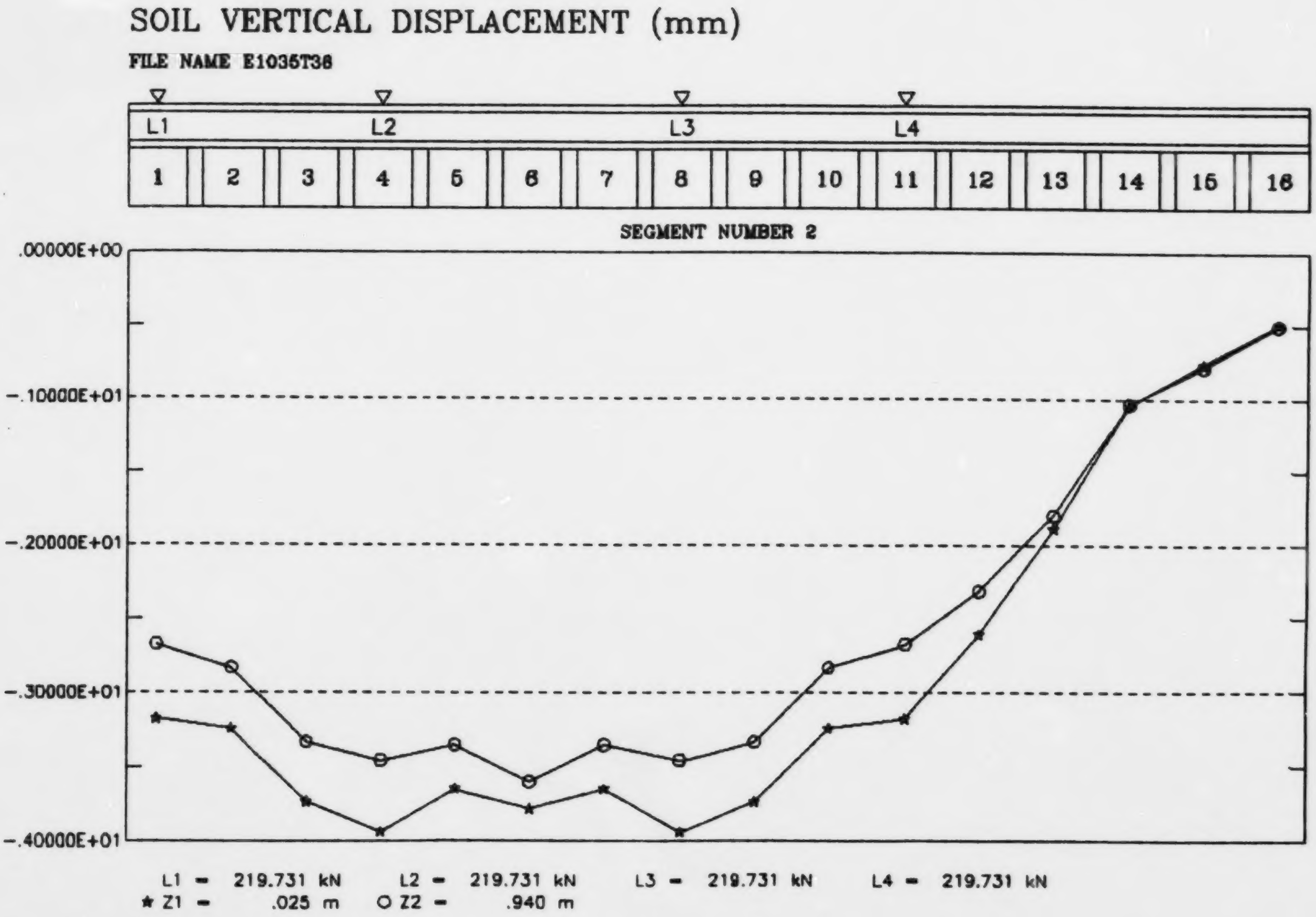


Figure 3.8 GEOPLOT Soil Vertical Displacement

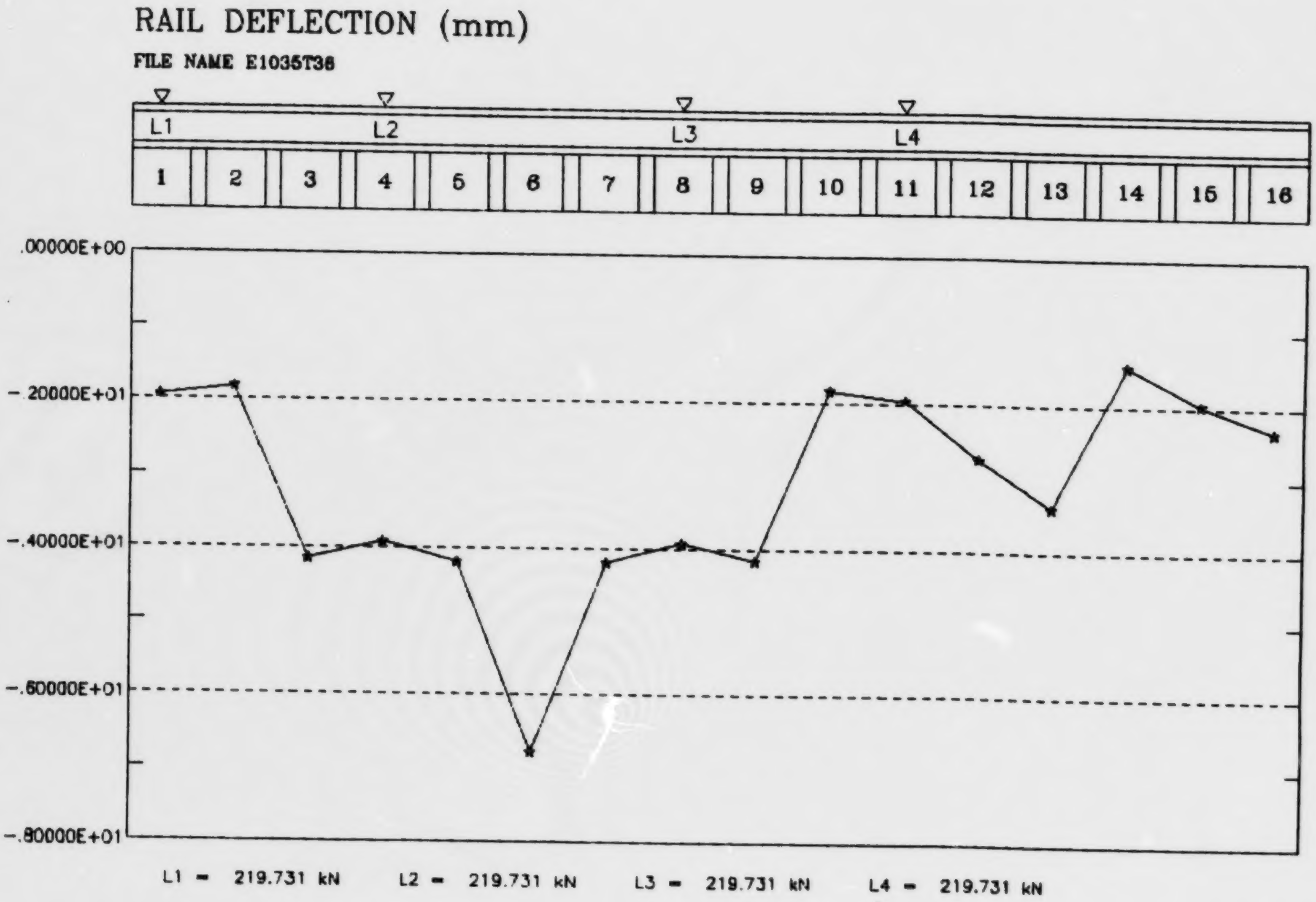


Figure 3.9 GEOPLOT Rail Deflection

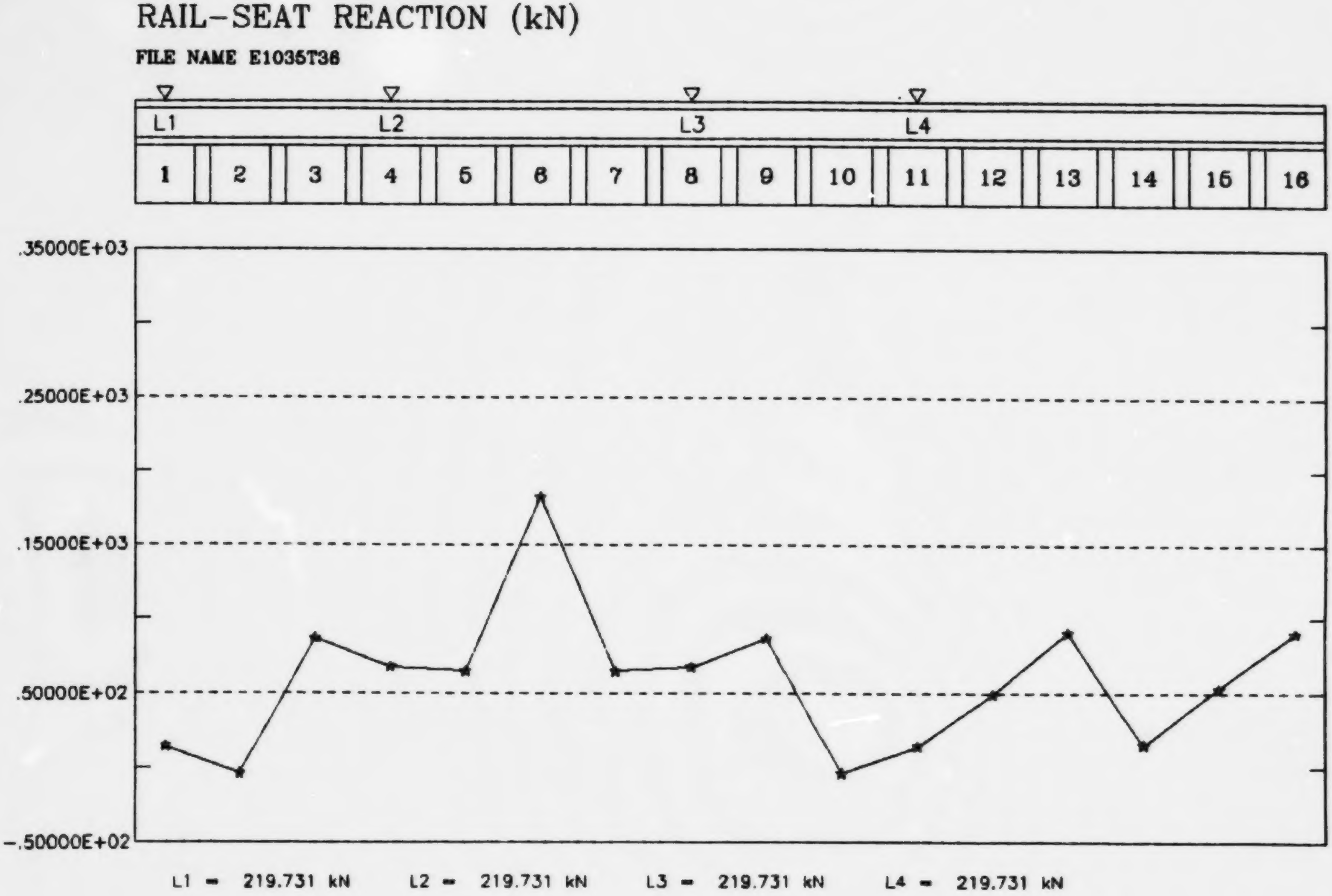


Figure 3.10 GEOPLOT Rail-Seat Reaction

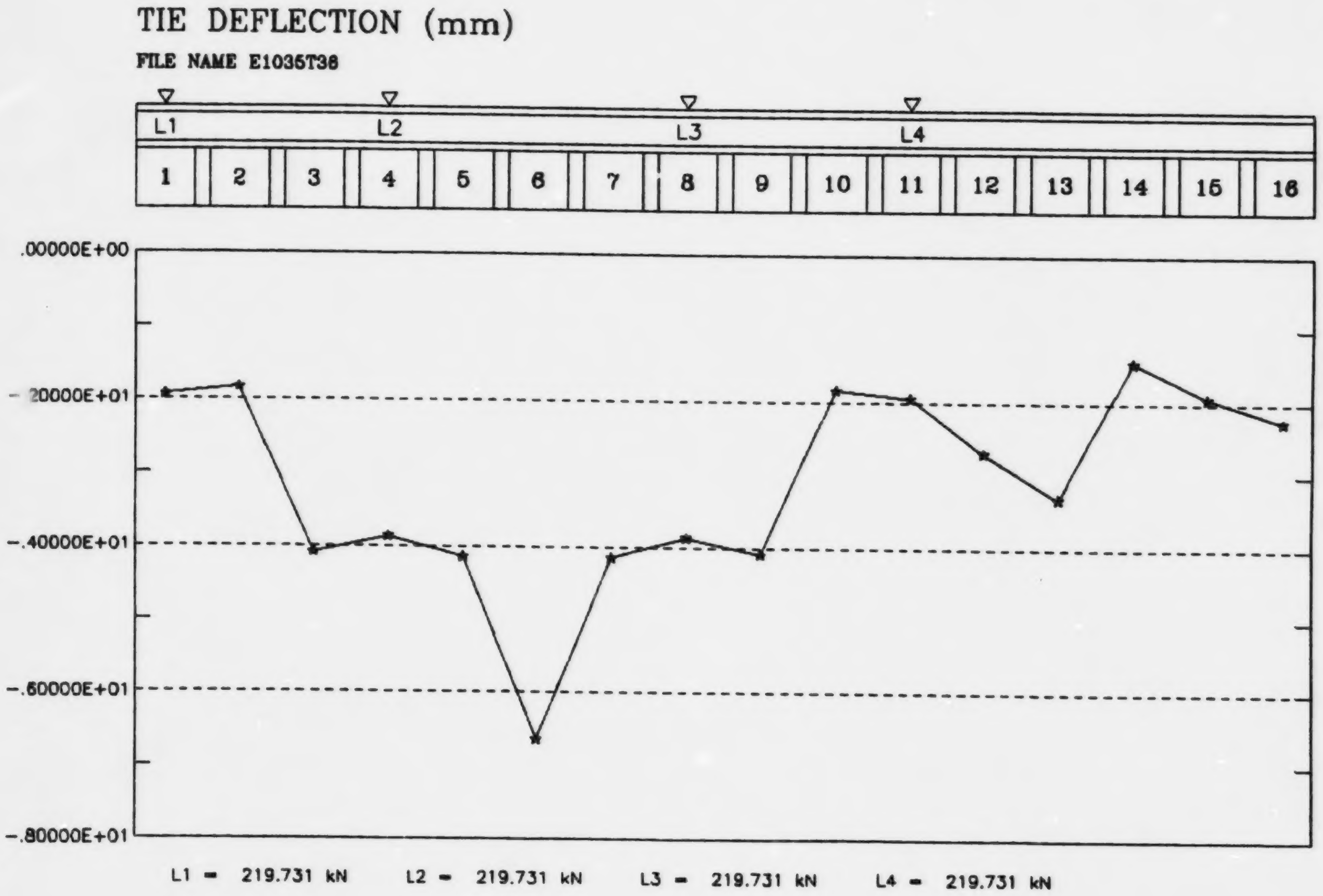


Figure 3.11 GEOPLOT Tie Deflection

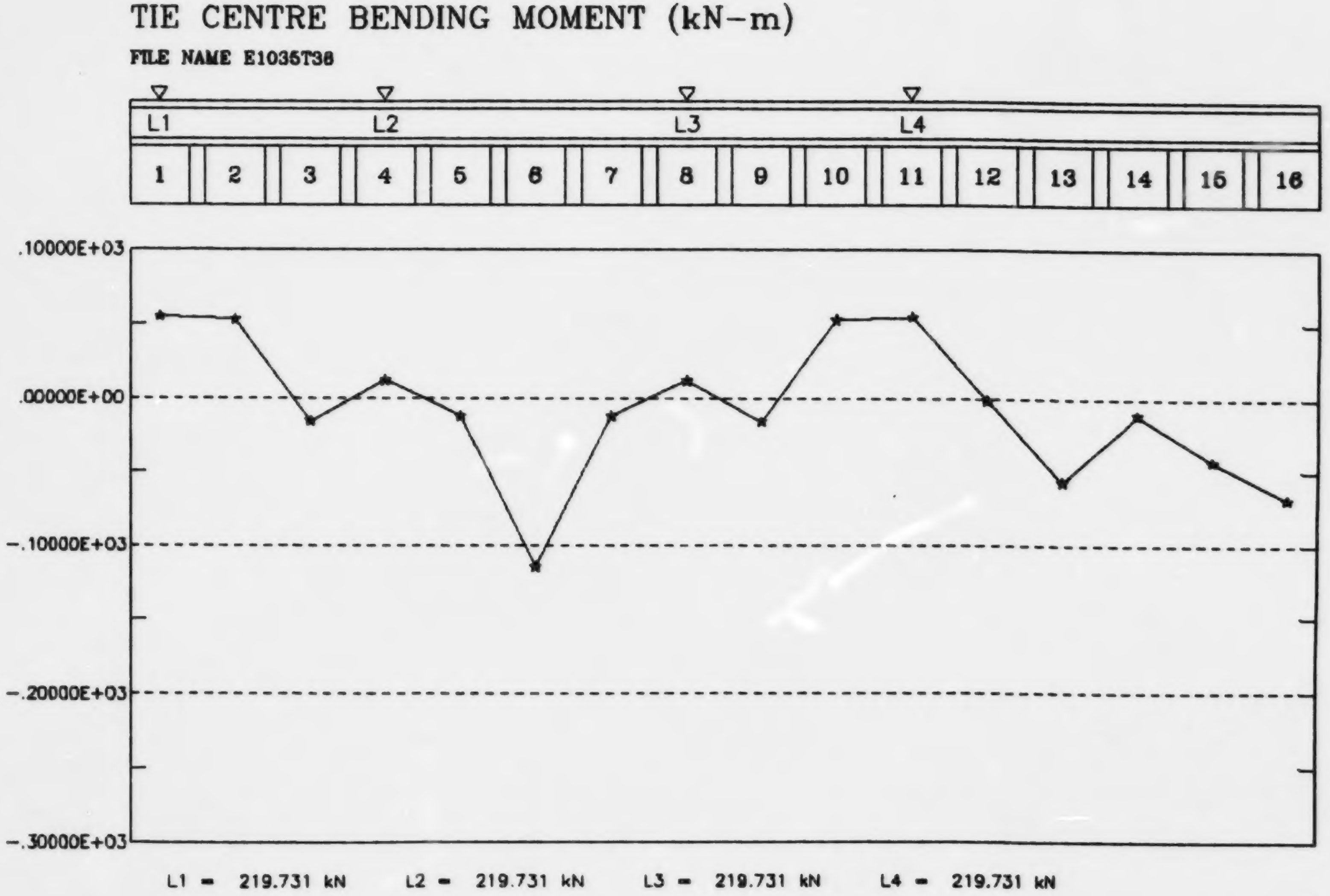


Figure 3.12 GEOPLOT Tie Center Bending Moment

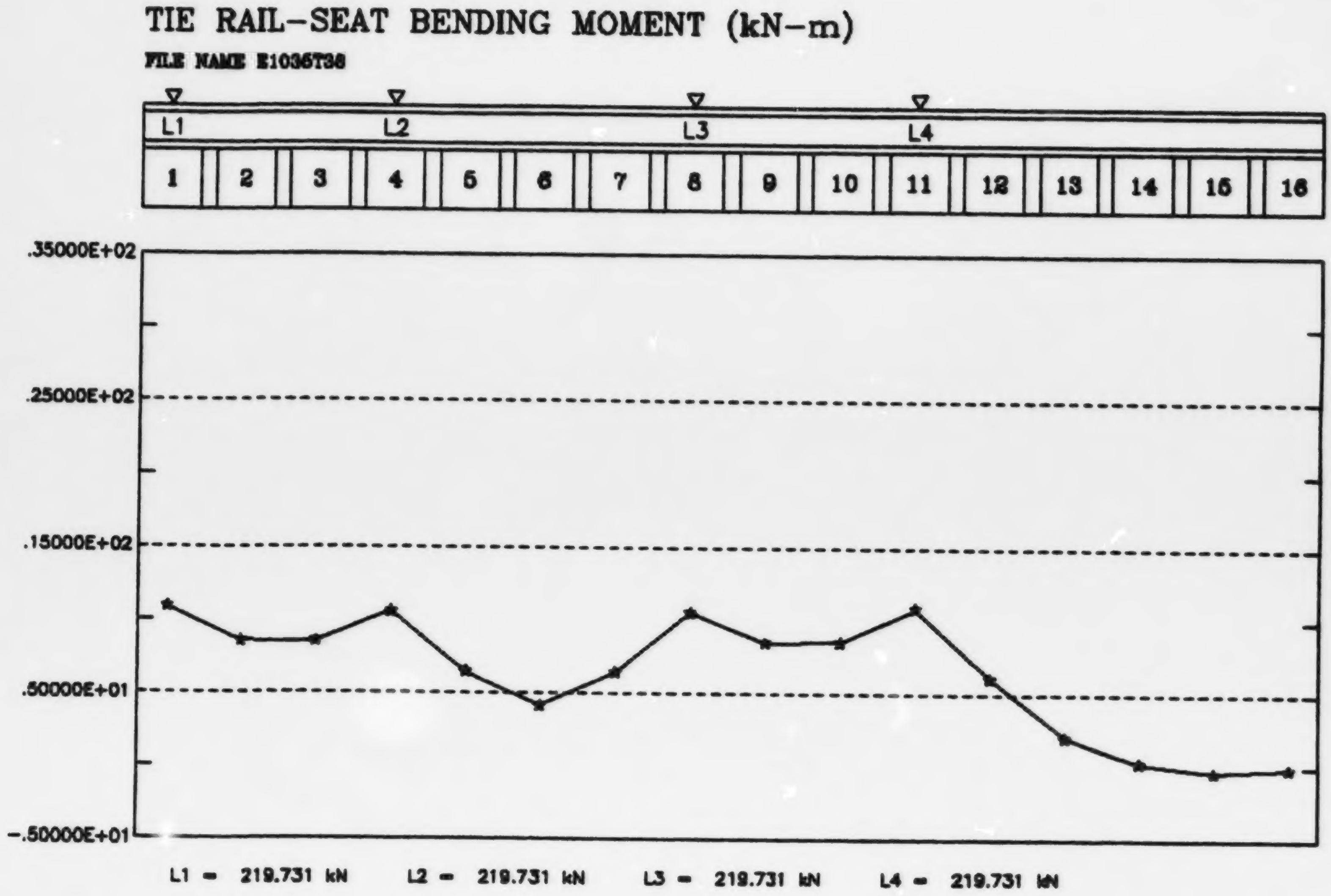


Figure 3.13 GEOPLOT Tie Rail-Seat Bending Moment

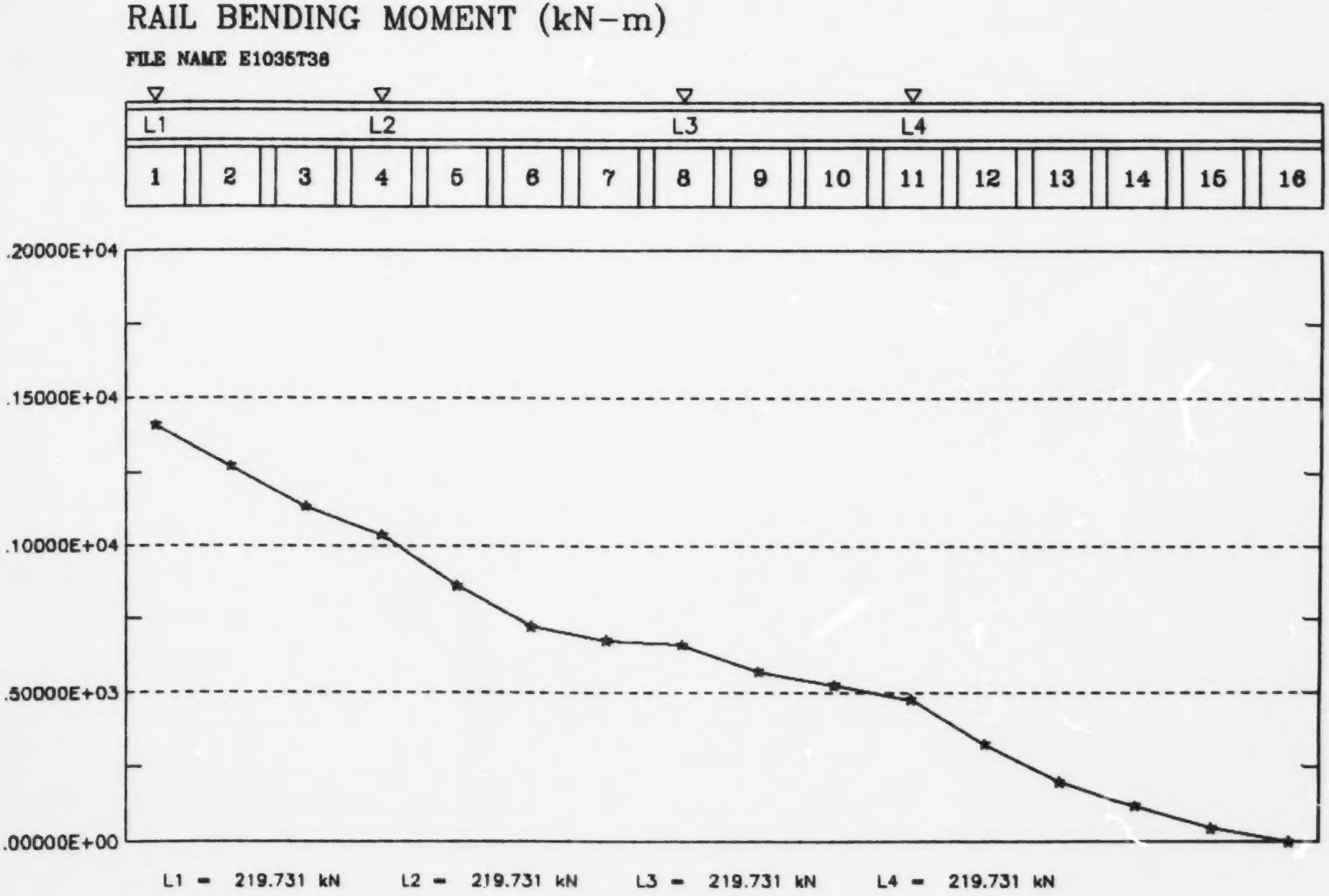


Figure 3.14 GEOPLOT Rail Bending Moment

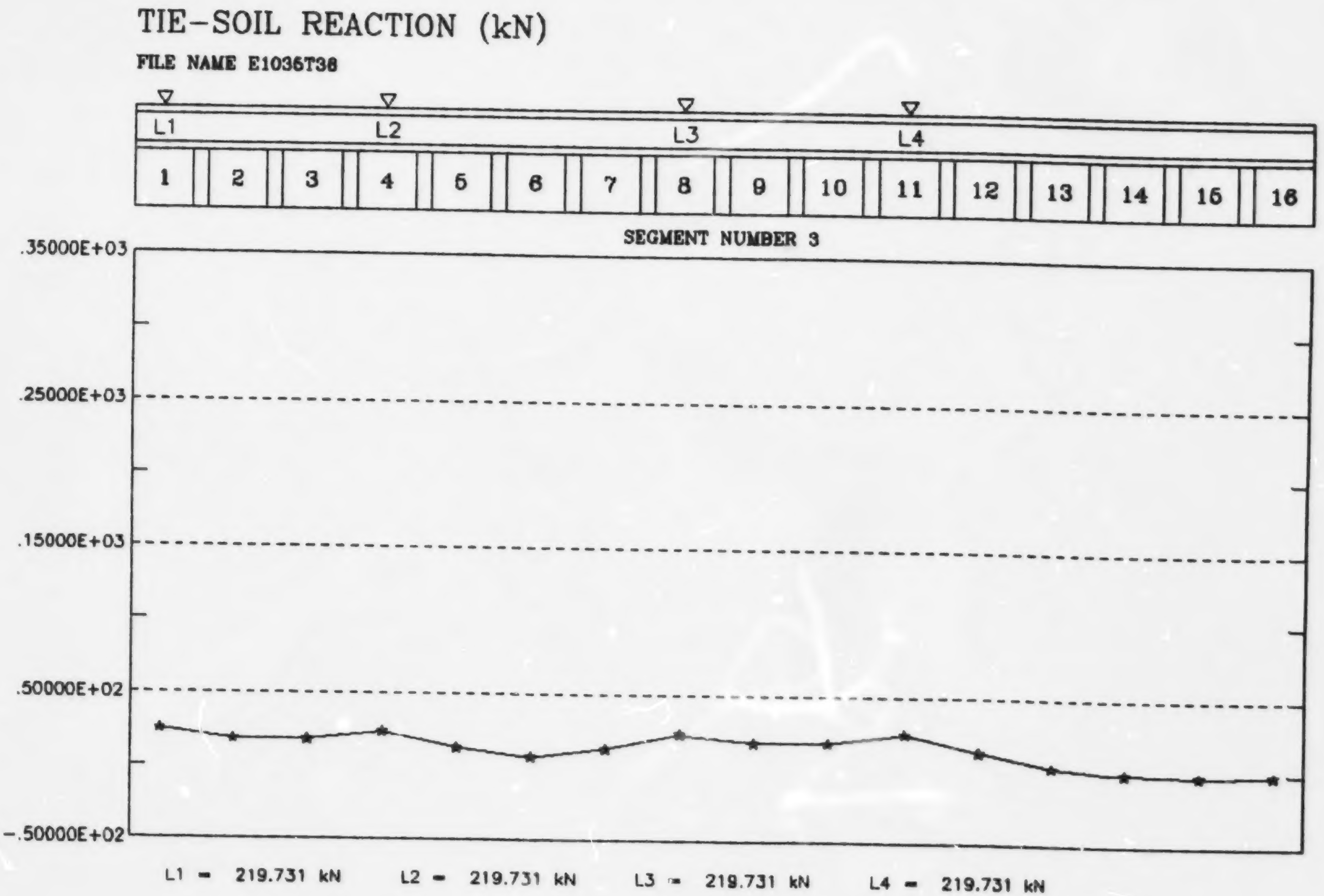


Figure 3.15 GEOPLOT Tie-Soil Reaction

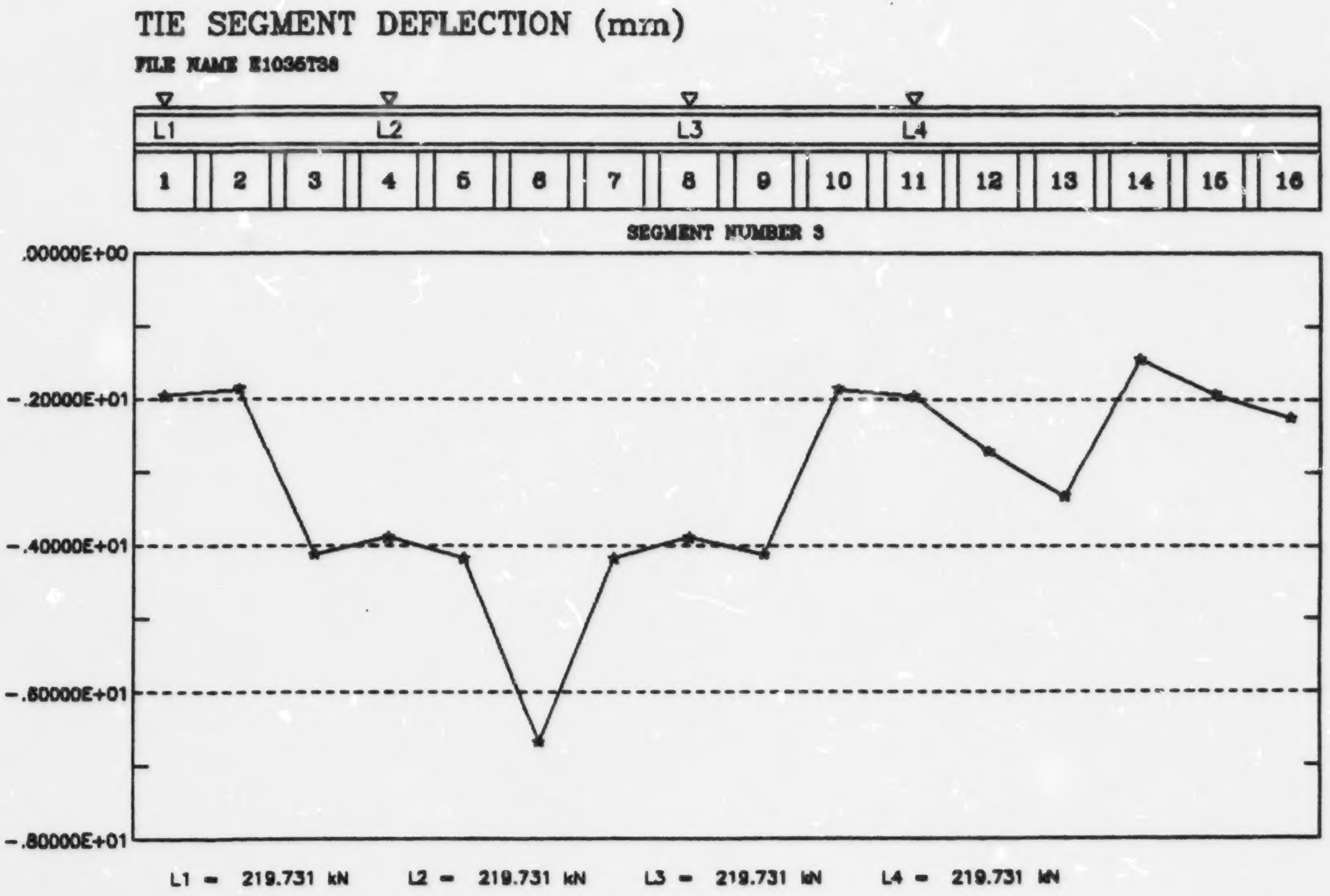


Figure 3.16 GEOPLOT Tie Segment Deflection

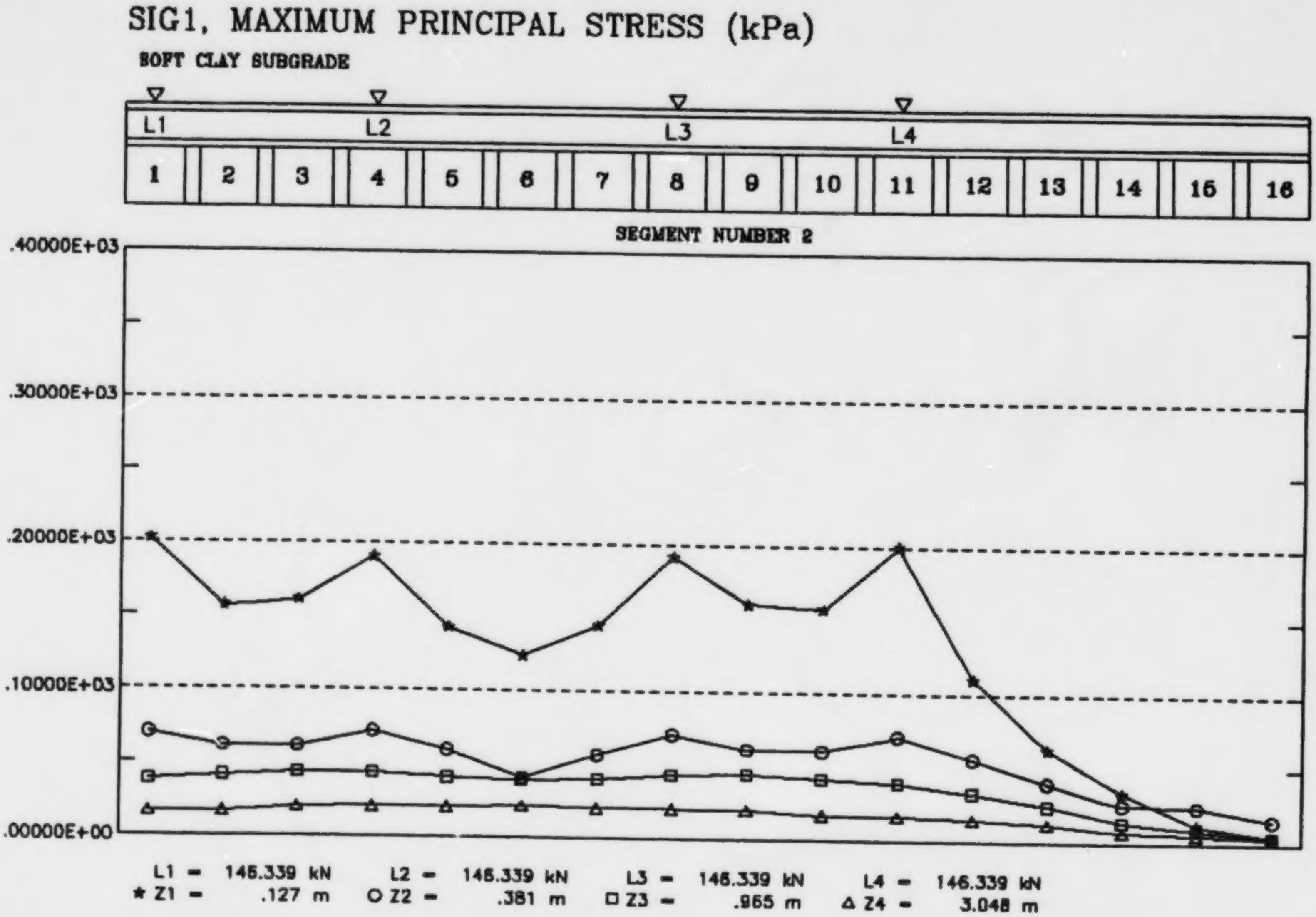


Figure 3.17 GEOPLOT Maximum Principal Stress Parallel to the Track

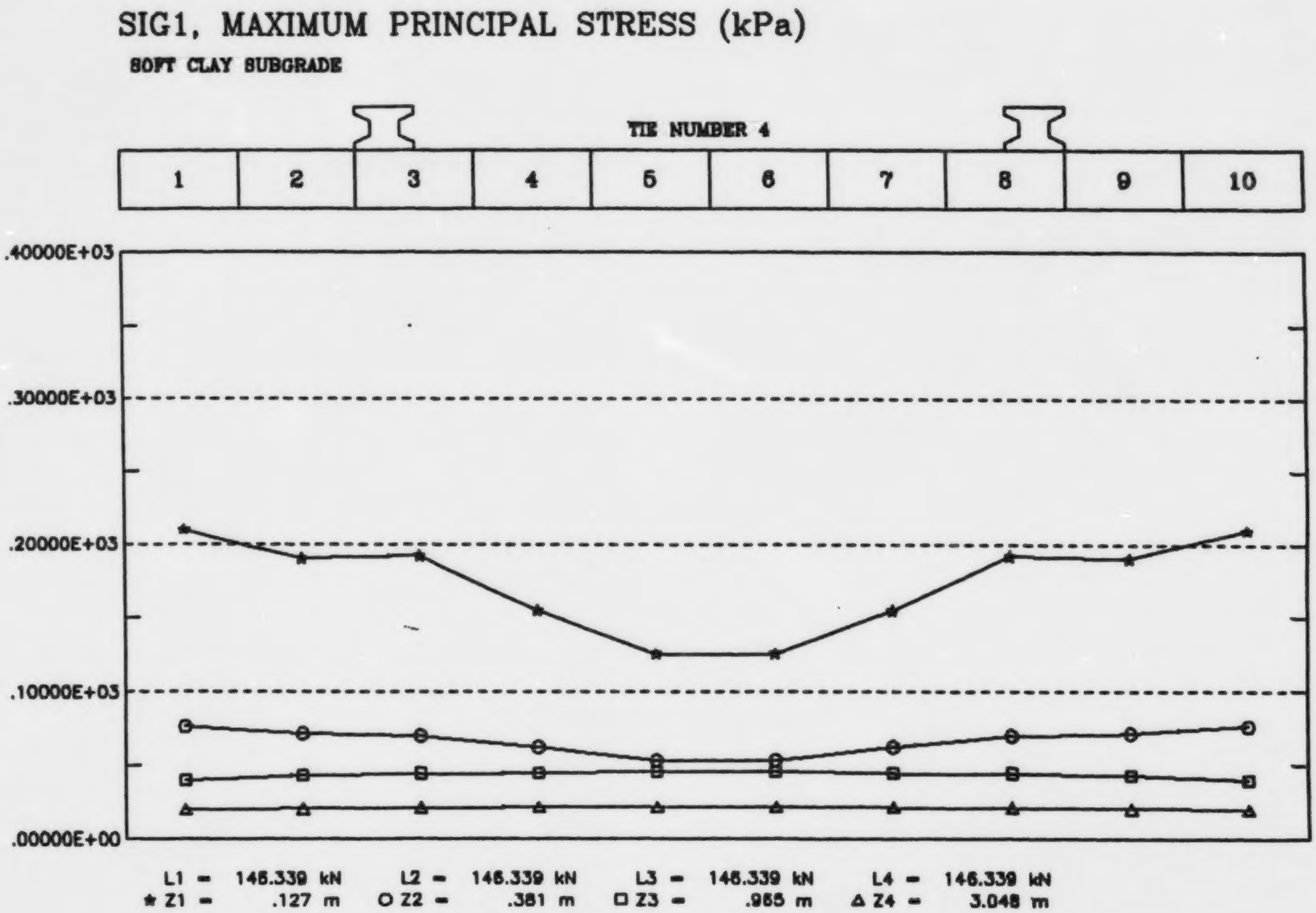


Figure 3.18 GEOPLOT Maximum Principal Stress Perpendicular to the Track

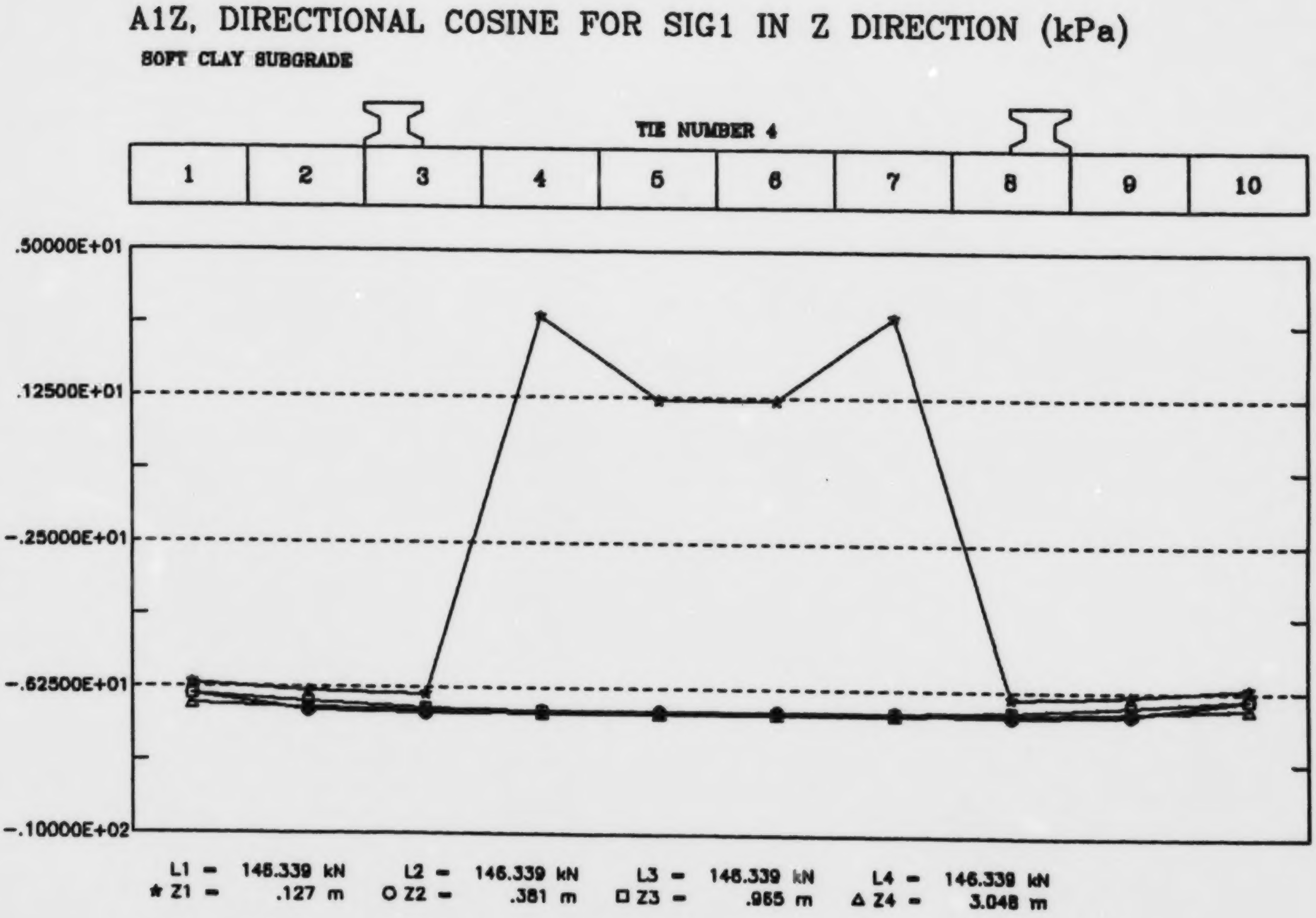


Figure 3.19 GEOPLOT Directional Cosine for the Maximum Principal Stress in the Z-direction

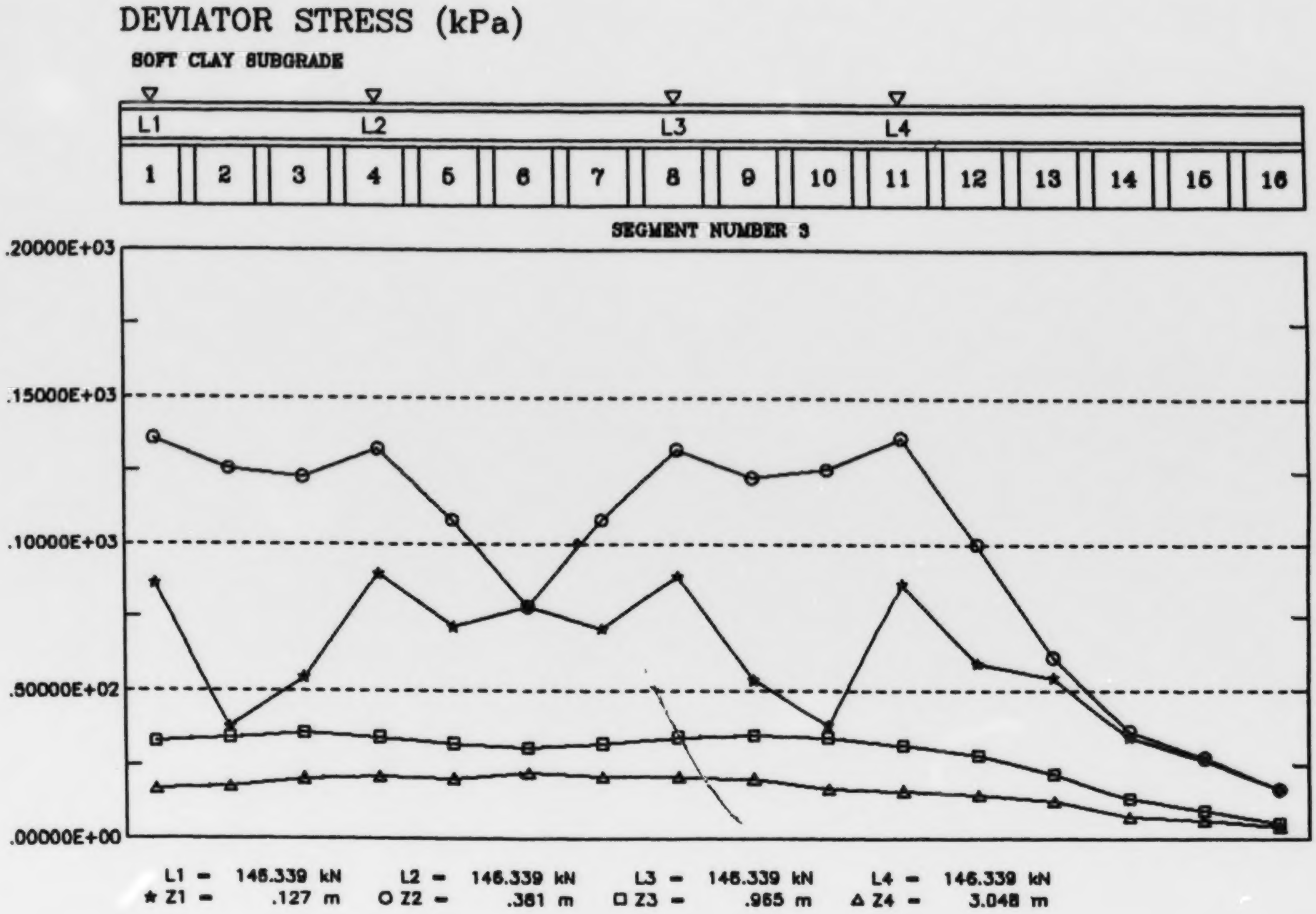


Figure 3.20 GEOPLOT Deviator Stress

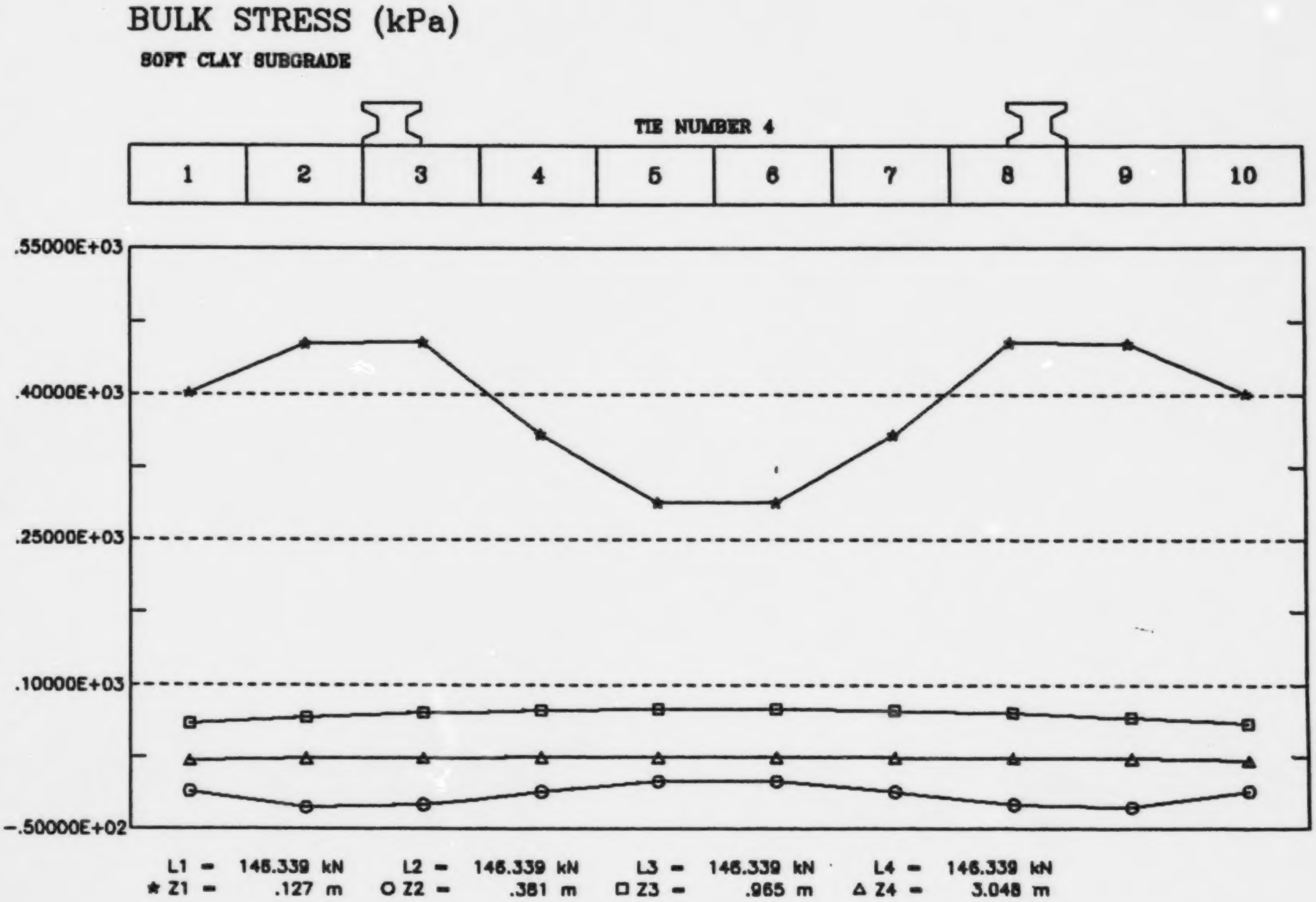


Figure 3.21 GEOPLOT Bulk Stress

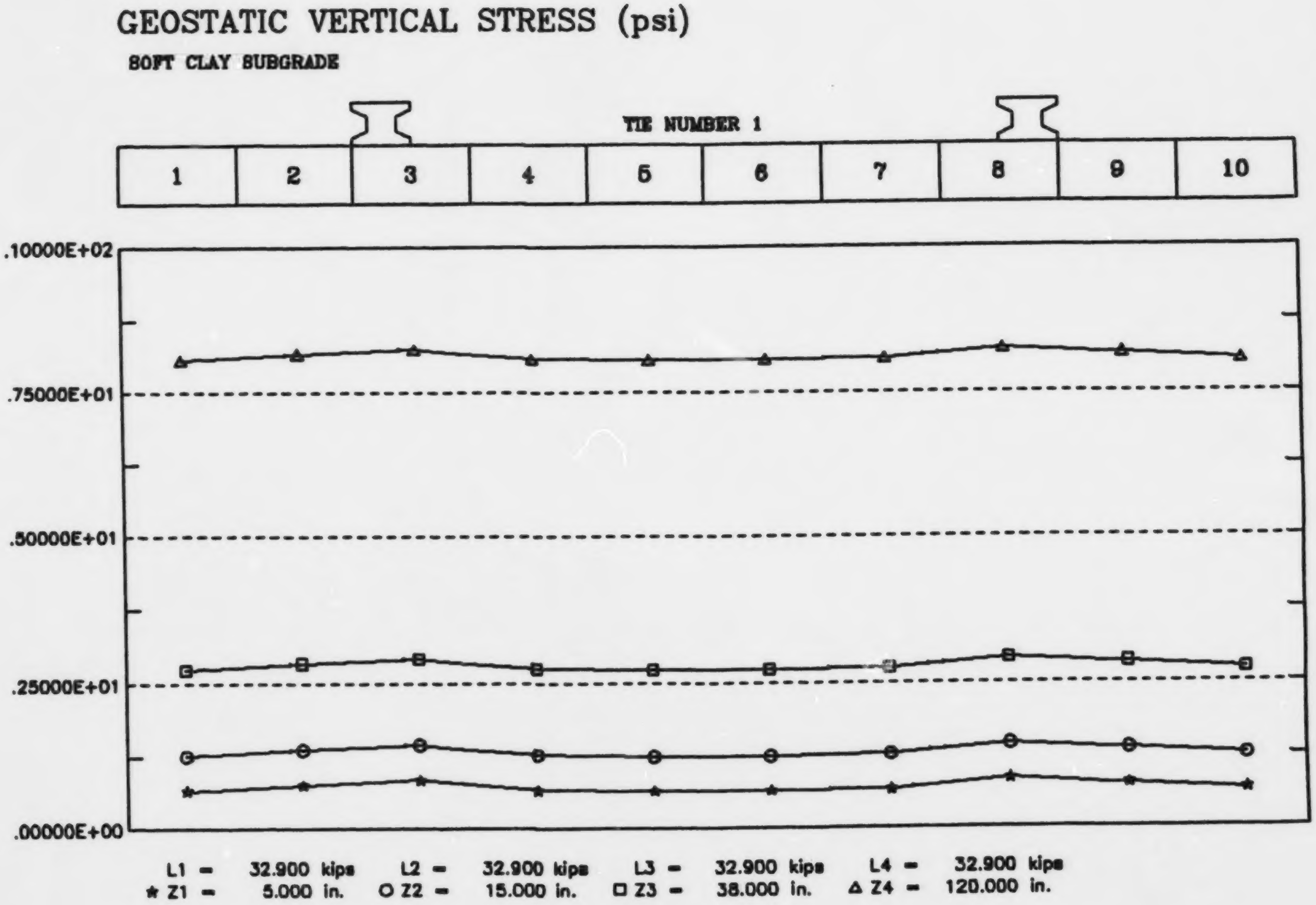


Figure 3.22 GEOPLOT Geostatic Vertical Stress

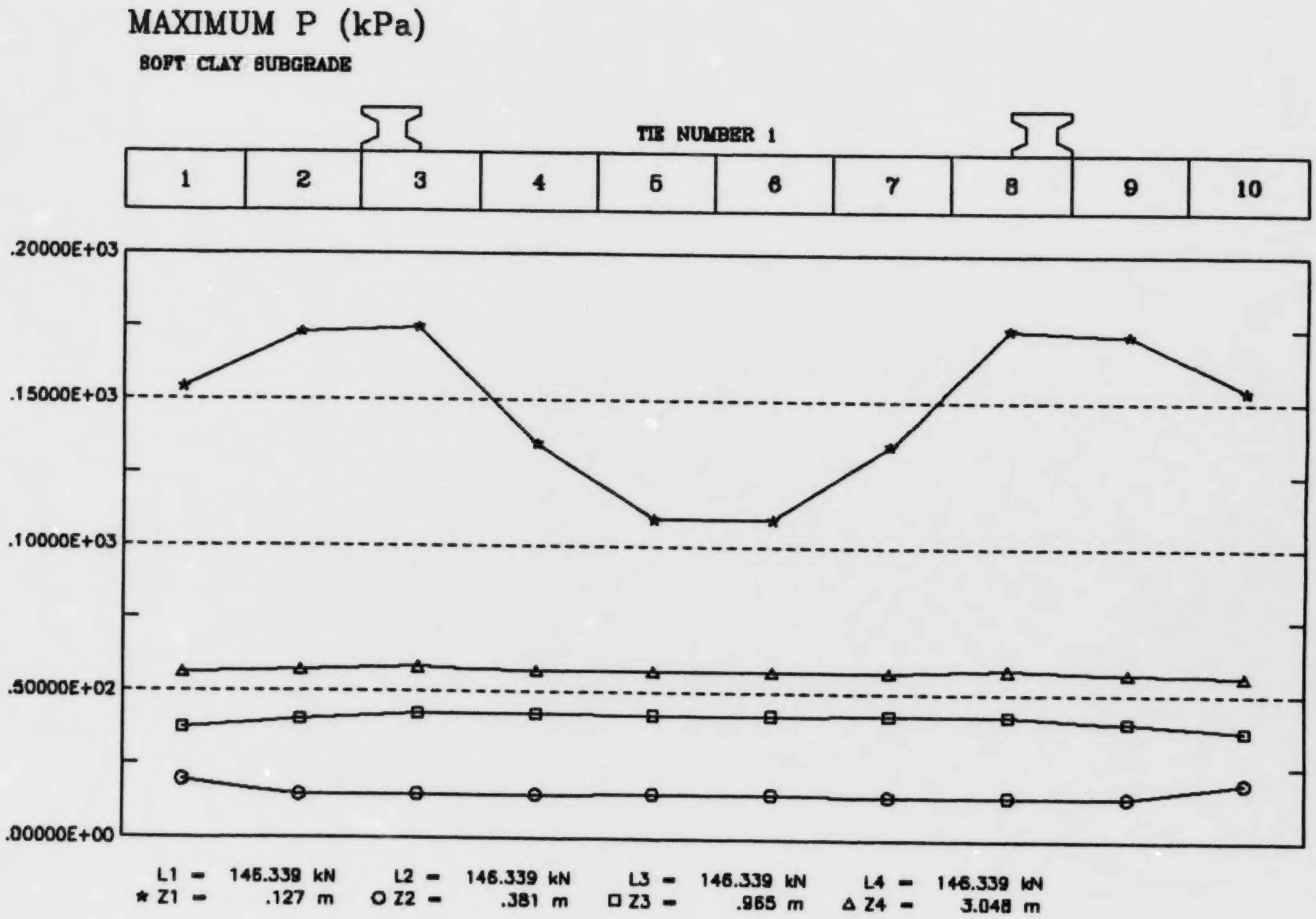


Figure 3.23 GEOPLOT Maximum p

Options 0 to 8 from the first menu do not present sub-options. Figure 3.9 shows the rail deflection generated by requesting option 1. Figure 3.10 shows the rail-seat reaction generated by option 2. Similarly, the results of options 3 and 4 are presented in Figures 3.11 and 3.12, the tie deflection and tie centre bending moment, respectively.

The tie rail-seat bending moment is shown for option 5 in Figure 3.13. Option 6 is presented in Figure 3.14 as the rail bending moment. The tie soil reaction for option 7 is presented in Figure 3.15 and the tie segment deflection is presented in Figure 3.16.

Within plotting menu option 10, soil incremental principal stresses, the maximum, mimimum and intermediate principal stresses are available for plotting. In addition, the directional cosines defining the principal stresses can be plotted. Figure 3.17 shows the maximum principal stress plotted by segment number for segment number 2 for an example soft clay subgrade. Figure 3.18 shows the maximum principal stress plotted by tie number for tie number 4 for an example soft clay subgrade. Figure 3.19 represents the directional cosine for the maximum principal stress in the Z-direction.

Figure 3.20 presents the deviator stress (i.e., the maximum principal stress minus the minimum principal stress) for an example soft clay subgrade. Figure 3.21 presents the bulk stress (i.e., the sum of the principal stresses) for an example soft clay subgrade. Figures 3.17 through 3.21 would be produced by the options available within option 10.

Within option 11, the soil equivalent triaxial stresses, the geostatic vertical stress (presented in Figure 3.22), the octahedral stresses and the equivalent triaxial stresses are available for plotting. The stresses are defined in terms of p and q rather than the principal stresses and Mohr circle. Soil mechanics texts define p and q as follows:

$$p = \frac{\sigma_1 + \sigma_3}{2} \qquad [1]$$

$$q = \frac{\sigma_1 - \sigma_3}{2} \qquad [2]$$

where σ_1 = the maximum principal stress
σ_3 = the minimum principalstress

An example plot of the maximum p is presented in Figure 3.23.

STRESS USER'S MANUAL

4.0 User's Manual for the STRESS Computer Program

The STRESS computer program was developed at the University of Saskatchewan to use the GEOTRACK stress modelling capabilities in a bearing capacity approach to railway design. The computer program STRESS is limited to use in the two bearing capacity approaches to railway design which have been documented in the final report (1).

4.1 Introduction to the STRESS Computer Program

STRESS is an interactive post-processing computer package which averages the ballast and subgrade surface stress distributions which are output from the GEOTRACK computer program. The computer program STRESS was written to aid in the development of the bearing capacity design charts presented in the final report (1) and can be used to create additional design charts, as desired. If the user does not wish to develop further design charts, the role of the computer program STRESS is limited to providing further detail on the stress averaging techniques described in the body of the final report (1).

The purpose of the STRESS computer program is: 1) to analyze the GEOTRACK output file to determine if the stress output generated can be used for the stress analysis portion of a bearing capacity approach to railway design, 2) to query the user for the desired Stress Averaging Technique or Bearing Capacity Option, 3) to read and average the vertical stresses which occur at the ballast surfae and the subgrade surface according to the desired Stress Averaging Technique or Bearing Capacity Option, and 4) to write to an output file the pertinent information regarding the file upon which the averaging was performed and the resultant average.

4.2 Description of the STRESS Computer Program

A general algorithm for STRESS is presented in Figure 4.1. The first few steps are similar to the front end of the GEOPLOT post-processing graphics package. The screen display "STRESS" informs the user which program is being executed. Prompts for the drive and directory, GEOTRACK output file name and the '.STR' file to be created set up the files to be used by the STRESS program.

The essence of the STRESS program is the choice of the Stress Averaging Technique or Bearing Capacity Options. Figures 4.2 through 4.5 illustrate the Options 1 through 4. Option 1 Stress Averaging Technique is reserved for comparison to a bearing capacity value computed for Option 1 Bearing Capacity. Similarly, Option 2 Stress Averaging Technique is reserved for Option 2 Bearing Capacity. The same is true for Options 3 and 4. The computer program COMPARE, which is described in Section 6, contains user-friendly checks to ensure that the Stress Averaging Technique Options are compatible with the bearing capacity values calculated by the program, BEARING (described in Section 5).

After user input of the desired Stress Averaging Technique, the computer program, STRESS, searches the GEOTRACK output file for the appropriate data and loads the data into array memory for calculation of the average stresses. The user is prompted for a 70 character comment line which will be attached to the STRESS output file. The average stresses and pertinent information are written to the STRESS output file. The STRESS output file can then be used as input to the computer program, COMPARE, for the purposes of creating bearing capacity factor of safety design charts (Figure 1.1).

1) Display name of program.

2) Input drive and directory, name of GEOTRACK output file and name for '.STR' file to be created.

3) Input desired Stress Averaging Technique or Bearing Capacity Option, choice of 1 through 4.

4) Locate and read the desired data into arrays in computer memory.

5) Input desired comments on one line.

6) Compute the average stress on the data in arrays, according to the requested Stress Averaging Technique.

7) Write the output to the '.STR' file and display message to the screen indicating that the averaging is complete.

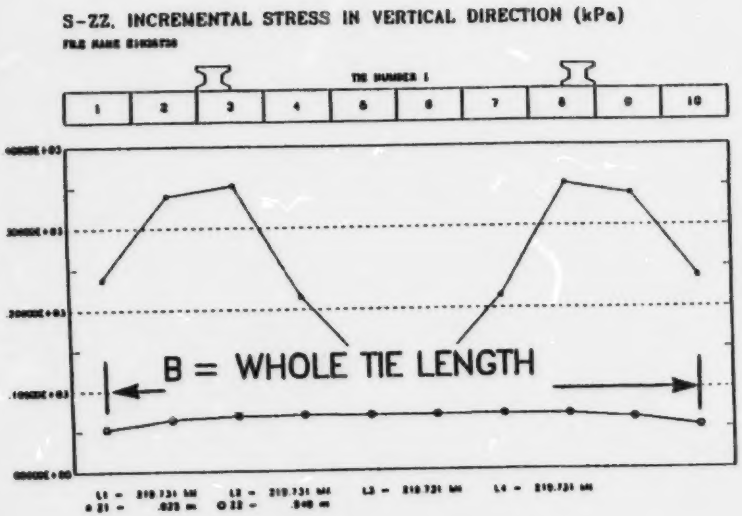
8) Ask if user wishes to run program again. If yes, start over at item 1). If not, exit from the program.

Figure 4.1 General Algorithm for STRESS Computer Program

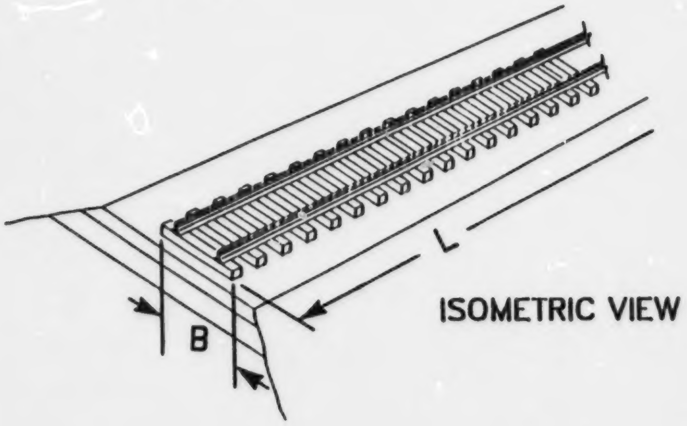
OPTION 1

AVERAGE OF SUBGRADE SURFACE STRESSES
FOR WHOLE TIE LENGTH

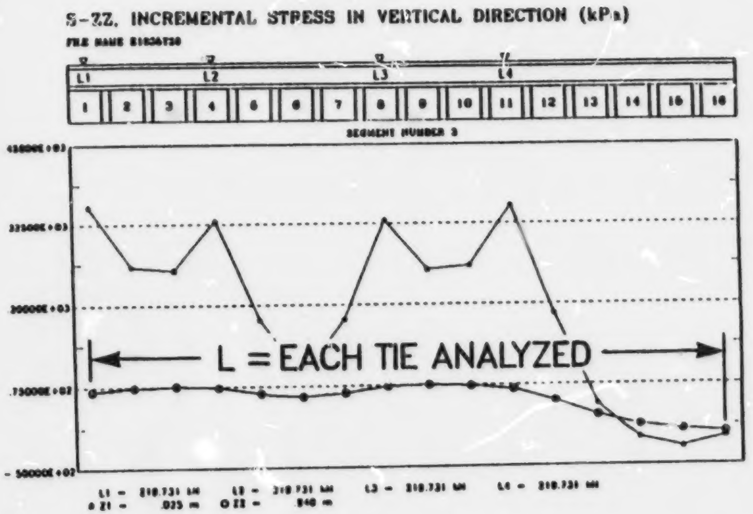
FOR EACH TIE ANALYZED
ALONG LENGTH OF TRACK



CROSS-SECTIONAL VIEW



ISOMETRIC VIEW



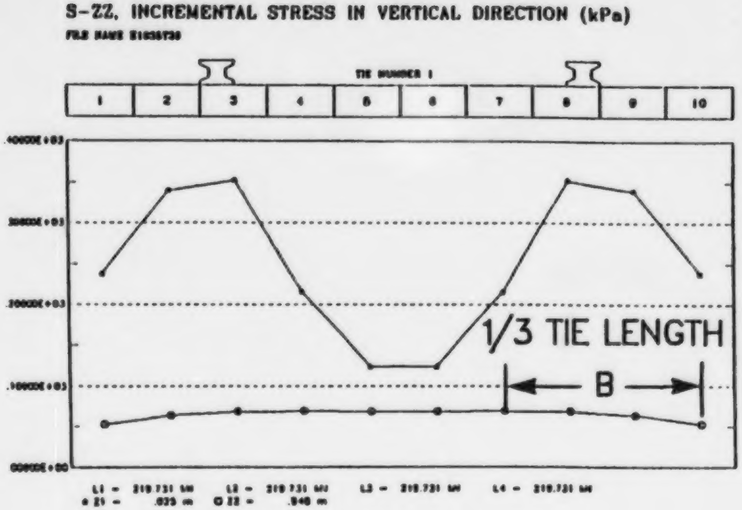
LONGITUDINAL VIEW

Figure 4.2 Option 1 "Stress Averaging Technique"

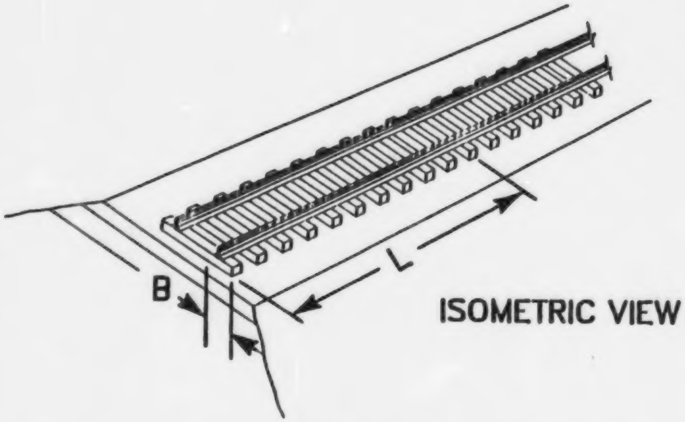
OPTION 2

AVERAGE OF SUBGRADE SURFACE STRESSES
FOR 1/3 TIE LENGTH

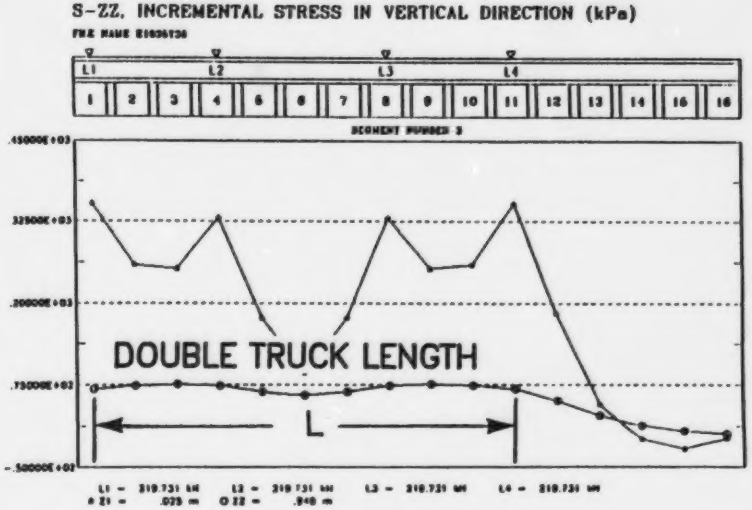
FOR EACH TIE
WITHIN LENGTH OF DOUBLE TRUCK



CROSS-SECTIONAL VIEW



ISOMETRIC VIEW



LONGITUDINAL VIEW

Figure 4.3 Option 2 "Stress Averaging Technique"

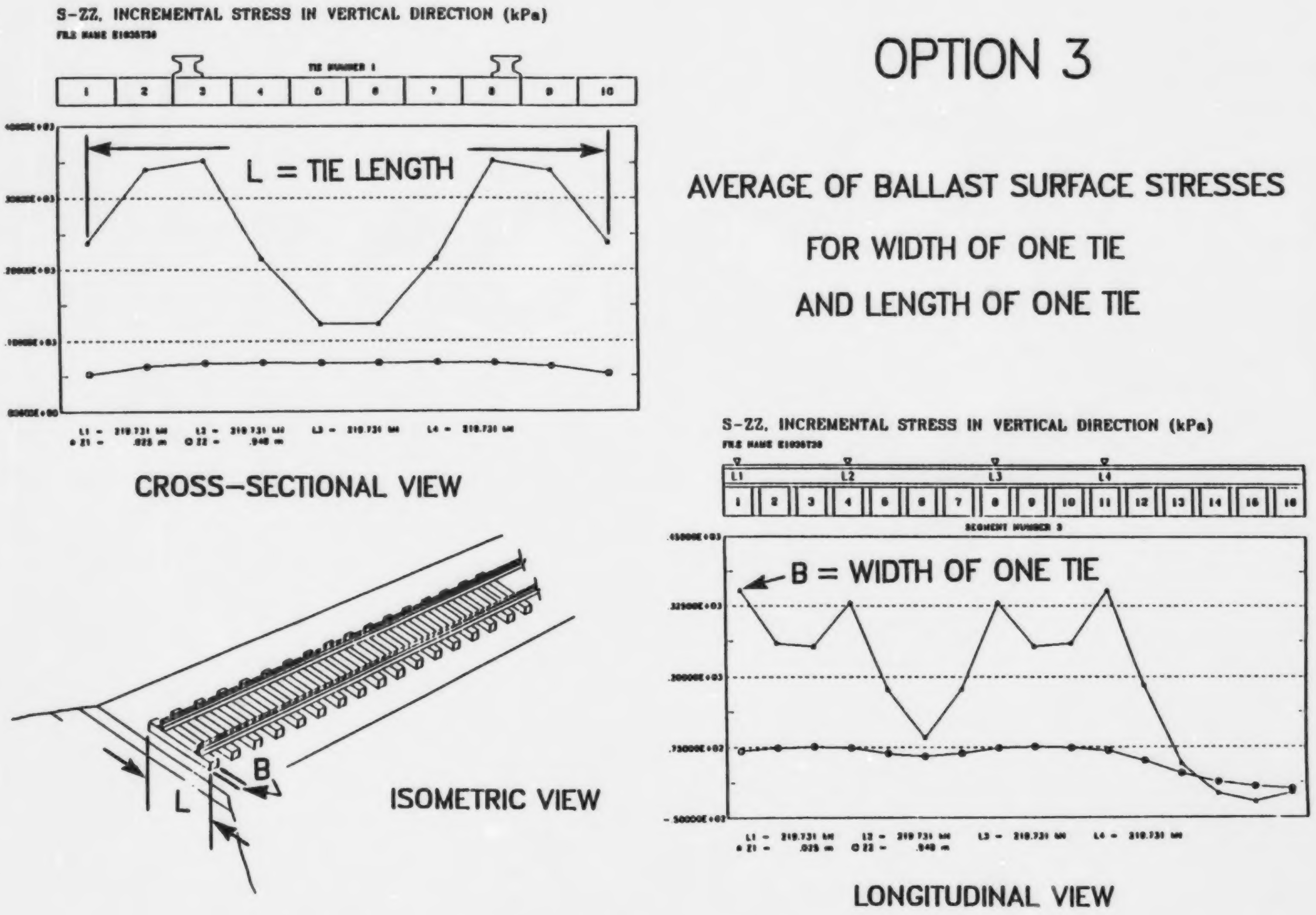


Figure 4.4 Option 3 "Stress Averaging Technique"

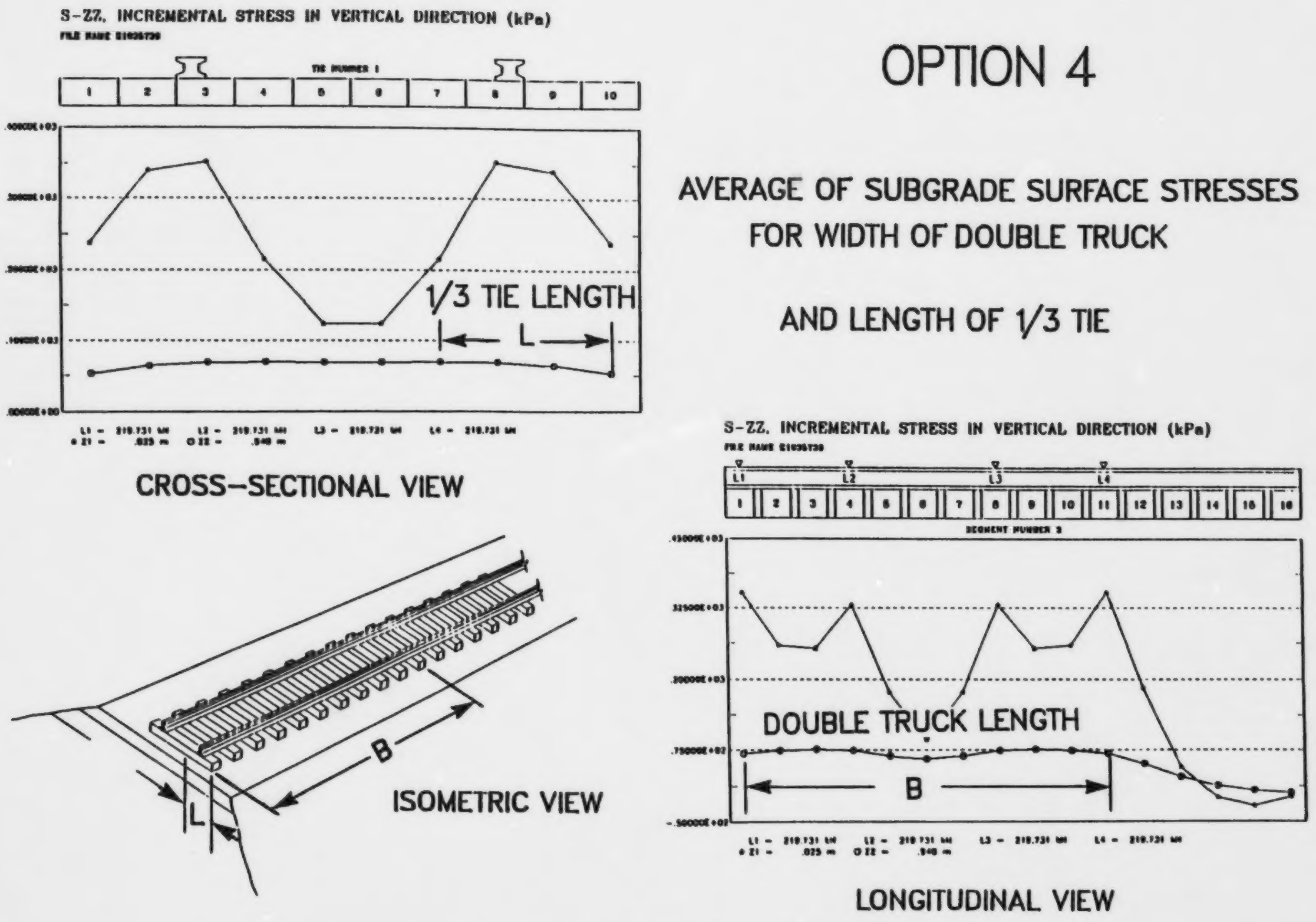


Figure 4.5 Option 4 "Stress Averaging Technique"

4.3 Screen Displays and User Responses

The following few pages detail the user responses which are required to the computer program STRESS. Utilization of Option 3 will result in the requirement of an answer for one additional question. The user will be asked for which tie the stress averaging is to be performed. Figure 4.8 was the result of averaging on tie number 1.

```
         SSSSSSSS  TTTTTTTT  RRRRRRR   EEEEEEEE  SSSSSSSS    SSSSSSSS
         SSSSSSSS  TTTTTTTT  RRRRRRRR  EEEEEEEE  SSSSSSSS    SSSSSSSS
         SS           TT     RR    RR  EE        SS          SS
         SS           TT     RR    RR  EE        SS          SS
         SSSSSSSS     TT     RRRRRRRR  EEEEEE    SSSSSSSS    SSSSSSSS
         SSSSSSSS     TT     RRRRRRRR  EEEEEE    SSSSSSSS    SSSSSSSS
               SS     TT     RR    RR  EE              SS          SS
               SS     TT     RR    RR  EE              SS          SS
         SSSSSSSS     TT     RR    RR  EEEEEEEE  SSSSSSSS    SSSSSSSS
         SSSSSSSS     TT     RR    RR  EEEEEEEE  SSSSSSSS    SSSSSSSS

           STRESS  is a computer program which sets up a file
           containing averaged stresses computed with GEOTRACK.

                         University of Saskatchewan
                             Saskatoon, Canada.
                               ( Aug. 1988 )
---------------------------------------------------------------------------
DRIVE & DIRECTORY for Input/Output files ?
( e.g., C:, C:\WORK\, or BLANK for current DIR )...........:
INPUT  DATA FILE name ( Do not include .OGT )..............: E1035T36
OUTPUT DATA FILE name ( Do not include .STR )..............: OPTION1

    --- COMPUTATION OPTIONS ---

 ......BEARING CAPACITY PERPENDICULAR TO TRACK............

 ENTER 1 - Whole track: B=tie length, L=infinity..........
       2 - Whole track: B=1/3 tie length, L=double truck..

 .......BEARING CAPACITY PARALLEL TO TRACK................

 ENTER 3 - Individual tie: B=tie width, L=infinity........
       4 - Whole track: B=double truck, L=1/3 tie length..

       5 - EXIT............................................: 1

** Reading data, please wait **
```

```
Input COMMENT LINE for output file :
Averaged Stress for Option 1 on file E1035T36

===========Computations completed=============

The following data file has been generated :

          OPTION1.STR

Do you wish to run STRESS again ? Enter Y for yes..N
```

4.4 Typical Output Files

A typical '.STR' file for each option is illustrated in Figures 4.6 through 4.9. Output includes the name of the file itself, the name of the input file which was averaged, space for comments, the distribution and magnitude of the axle loads, the Stress Averaging Technique Option and the resulting average stress.

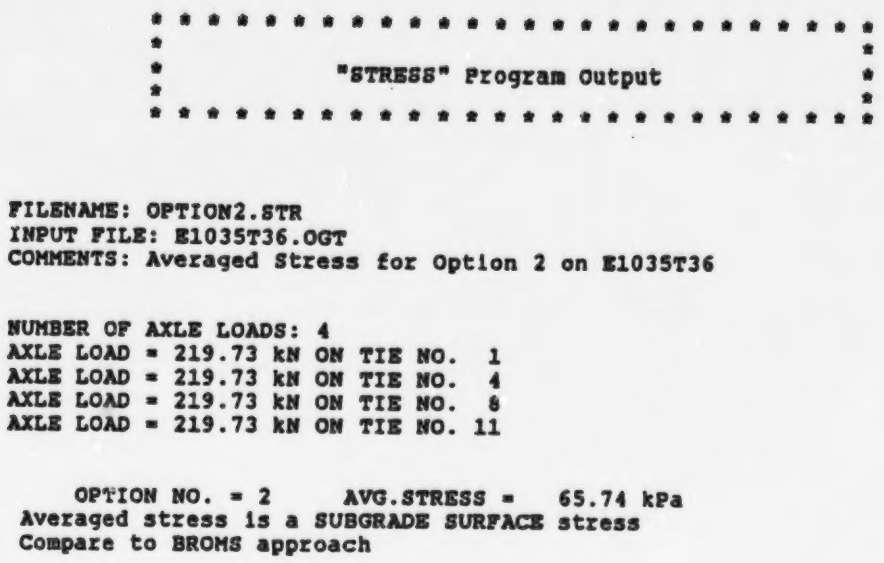
```
          * * * * * * * * * * * * * * * * * * * * * * * * * *
          *                                                 *
          *            "STRESS" Program Output              *
          *                                                 *
          * * * * * * * * * * * * * * * * * * * * * * * * * *


FILENAME: OPTION1.STR
INPUT FILE: E1035T36.OGT
COMMENTS: Averaged Stress for Option 1 on file E1035T36


NUMBER OF AXLE LOADS: 4
AXLE LOAD = 219.73 kN ON TIE NO.  1
AXLE LOAD = 219.73 kN ON TIE NO.  4
AXLE LOAD = 219.73 kN ON TIE NO.  8
AXLE LOAD = 219.73 kN ON TIE NO. 11


     OPTION NO. = 1     AVG.STRESS =   51.97 kPa
 Averaged stress is a SUBGRADE SURFACE stress
 Compare to BROMS approach
```

Figure 4.6 Option 1 Output from STRESS Program



```
* * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                 *
*            "STRESS" Program Output              *
*                                                 *
* * * * * * * * * * * * * * * * * * * * * * * * * *


FILENAME: OPTION2.STR
INPUT FILE: E1035T36.OGT
COMMENTS: Averaged Stress for Option 2 on E1035T36


NUMBER OF AXLE LOADS: 4
AXLE LOAD = 219.73 kN ON TIE NO.  1
AXLE LOAD = 219.73 kN ON TIE NO.  4
AXLE LOAD = 219.73 kN ON TIE NO.  8
AXLE LOAD = 219.73 kN ON TIE NO. 11


    OPTION NO. = 2     AVG.STRESS =   65.74 kPa
 Averaged stress is a SUBGRADE SURFACE stress
 Compare to BROMS approach
```

Figure 4.7 Option 2 Output from STRESS Program

```
* * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                   *
*              "STRESS" Program Output              *
*                                                   *
* * * * * * * * * * * * * * * * * * * * * * * * * * *


FILENAME: OPTION3.STR
INPUT FILE: E1035T36.OGT
COMMENTS: Averaged Stress for Option 3 on E1035T36


NUMBER OF AXLE LOADS: 4
AXLE LOAD = 219.73 kN ON TIE NO.  1
AXLE LOAD = 219.73 kN ON TIE NO.  4
AXLE LOAD = 219.73 kN ON TIE NO.  8
AXLE LOAD = 219.73 kN ON TIE NO. 11

     OPTION NO. = 3     AVG.STRESS =  253.69 kPa
  Averaged stress is a BALLAST SURFACE stress
  Compare to MEYERHOF and HANNA approach
```

Figure 4.8 Option 3 Output from STRESS Program

```
* * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                     *
*             "STRESS" Program Output                 *
*                                                     *
* * * * * * * * * * * * * * * * * * * * * * * * * * *


FILENAME: OPTION4.STR
INPUT FILE: E1035T36.OGT
COMMENTS: Averaged Stress for Option 4 on E1035T36

NUMBER OF AXLE LOADS: 4
AXLE LOAD = 219.73 kN ON TIE NO.  1
AXLE LOAD = 219.73 kN ON TIE NO.  4
AXLE LOAD = 219.73 kN ON TIE NO.  8
AXLE LOAD = 219.73 kN ON TIE NO. 11

     OPTION NO. = 4     AVG.STRESS =   65.74 kPa
 Averaged stress is a SUBGRADE SURFACE stress
 Compare to BROMS approach
```

Figure 4.9 Option 4 Output from STRESS Program

BEARING USER'S MANUAL

5.0 User's Manual for the BEARING Computer Progam

The BEARING computer program was developed at the University of Saskatchewan to calculate the bearing capacity for a bearing capacity approach to railway design. Although the results of the BEARING computer program are intended for use in developing further design charts (i.e., such as those presented in the final report (1)), the bearing capacity for any reasonable geometry beneath the tie-track structure may be computed.

5.1 Introduction to the BEARING Computer Program

BEARING is an interactive computer program which computes the bearing capacity of a ballast-subballast-subgrade system, as discussed in the final report (1). The computer program, BEARING, can be used to calculate the subgrade bearing capacity by a Broms approach (4) or the combined ballast-subgrade bearing capacity by a Hanna and Meyerhof approach (3). Figure 1.1 illustrates the use of the program BEARING in the development of the bearing capacity design charts.

1) Display name of program.

2) Input choice for calculation by Broms method or Hanna and Meyerhof method.

3) Input drive and directory, and name for '.BRG' file to be created.

4) Input a 70 character comment line.

5) Input the geometry data for the appropriate method, i.e., B, L and D for Broms method, and B, D and H for the Hanna and Meyerhof method.

6) Input the subgrade data: c, ϕ^1, ϕ^b and γ

7) Input the design subgrade matric suction: $(u_a - u_w)$

8) Input the ballast parameters: γ for Broms method and ϕ^1 and γ for the Hanna and Meyerhof method.

9) Check that the input data is correct. If desired, user may choose to re-enter data.

10) Compute bearing capacity factors.

11) Compute total cohesion.

12) Compute shape factors for Broms method and ballast bearing capacity for Hanna and Meyerhof method.

13) Compute ultimate subgrade bearing capacity by Broms method or ultimate combined ballast-subballast bearing capacity by Hanna and Meyerhof method. Write results to output file.

14) Ask if user wishes to run the program again.

Figure 5.1 General Algorithm for the BEARING Computer Program

5.2 Description of the BEARING Computer Program

Figure 5.1 illustrates the logic behind the BEARING computer program. The program determines which method the user desires for the calculations. Then, BEARING prompts the user for the required data input. If desired, the user is allowed to change any of the data after the data has been input.

Figures 5.2 through 5.5 illustrate the Bearing Capacity Options which may be compared to the Stress Averaging Technique Options presented in Section 4. If the user desires to compare the results of a '.STR' file to the results of a '.BRG' file, the user must ensure that the data values input to the program BEARING are compatible with the approximate dimensions illustrated in Figures 5.2 through 5.5 for the various Bearing Capacity Options. If the '.STR' files and the '.BRG' files are not compatible, the computer program, COMPARE, will detect the error and inform the user.

If the user does not wish to use the program, BEARING, to compute bearing capacity values for comparison to average stresses, then the user may use any reasonable values for the data input to the program, BEARING.

If the Broms approach (4) has been chosen for the calculations, the subgrade bearing capacity factors are computed. The total cohesion of the subgrade is calculated from the soil and suction data. Then, the nominal bearing capacity is determined and the appropriate modifying shape factors used to calculate the ultimate bearing capacity. The results are then written to the output file.

If the Hanna and Meyerhof approach (3) has been chosen for the calculations, the bearing capacity factors for the subgrade and for

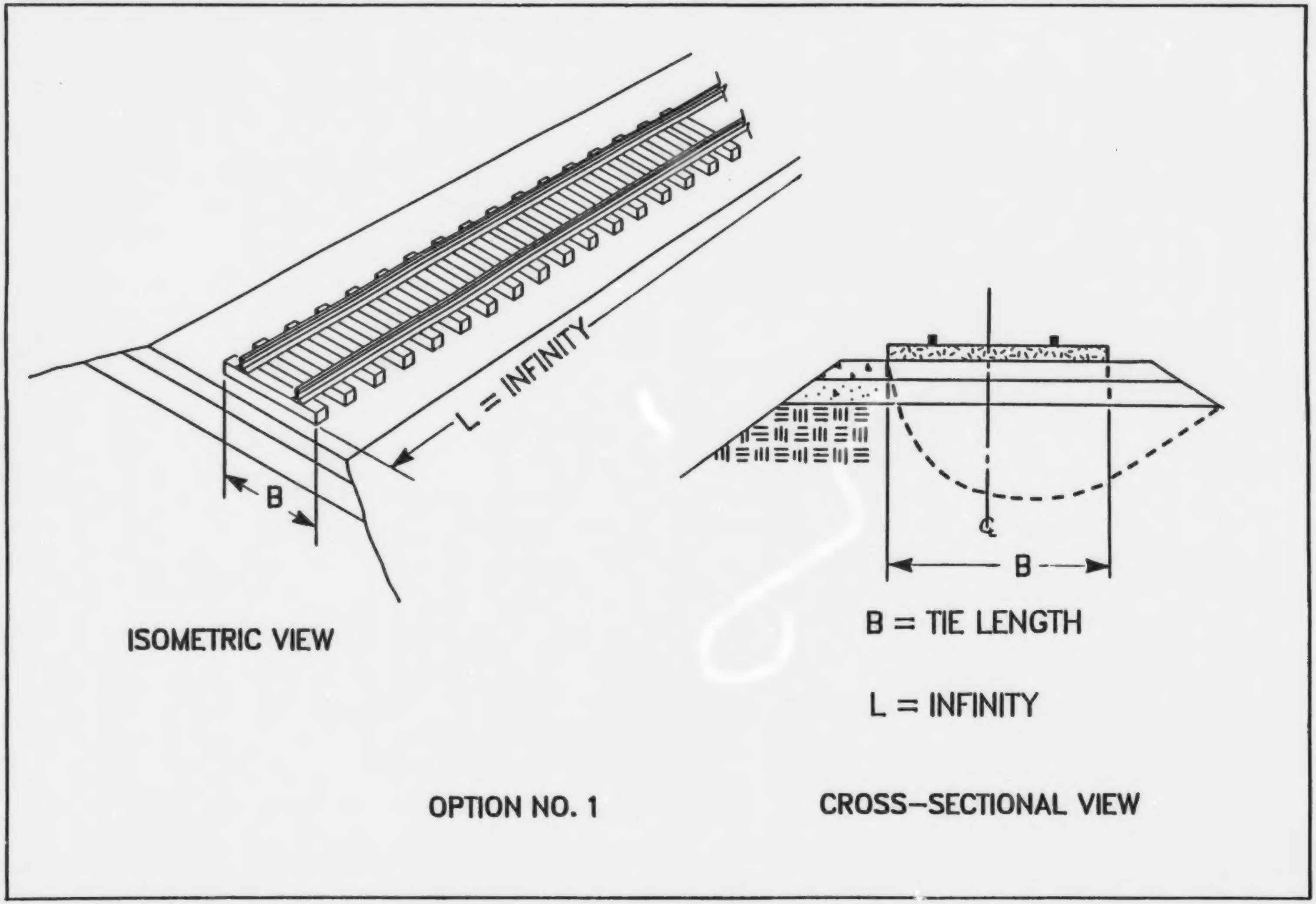

L = INFINITY
B
ISOMETRIC VIEW
B
B = TIE LENGTH
L = INFINITY
OPTION NO. 1
CROSS-SECTIONAL VIEW

Figure 5.2 Option 1 "Bearing Capacity Failure Geometry"

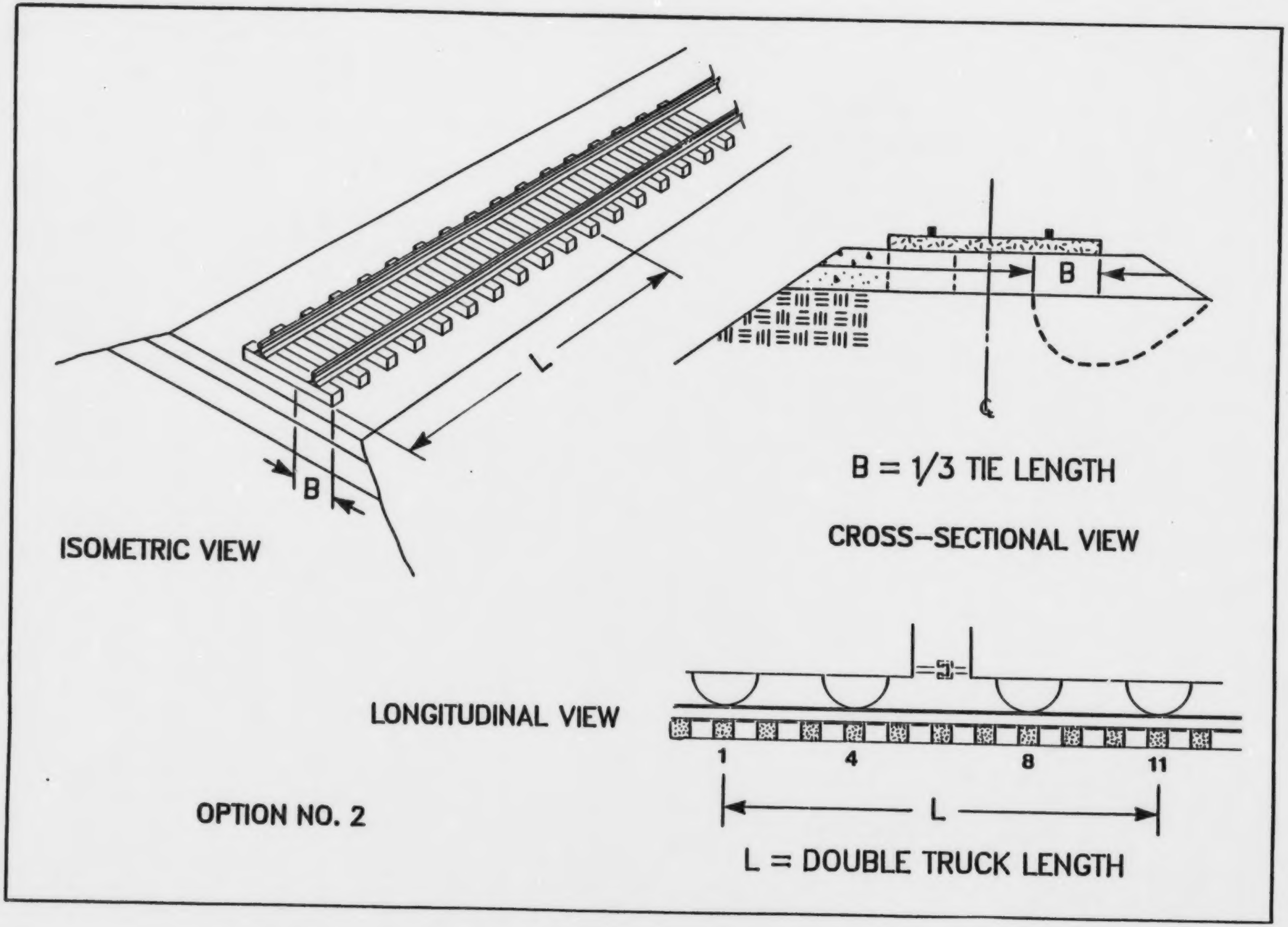

L
B
ISOMETRIC VIEW
B
℄
B = 1/3 TIE LENGTH
CROSS–SECTIONAL VIEW
LONGITUDINAL VIEW
1
4
8
11
L
L = DOUBLE TRUCK LENGTH
OPTION NO. 2

Figure 5.3 Option 2 "Bearing Capacity Failure Geometry"

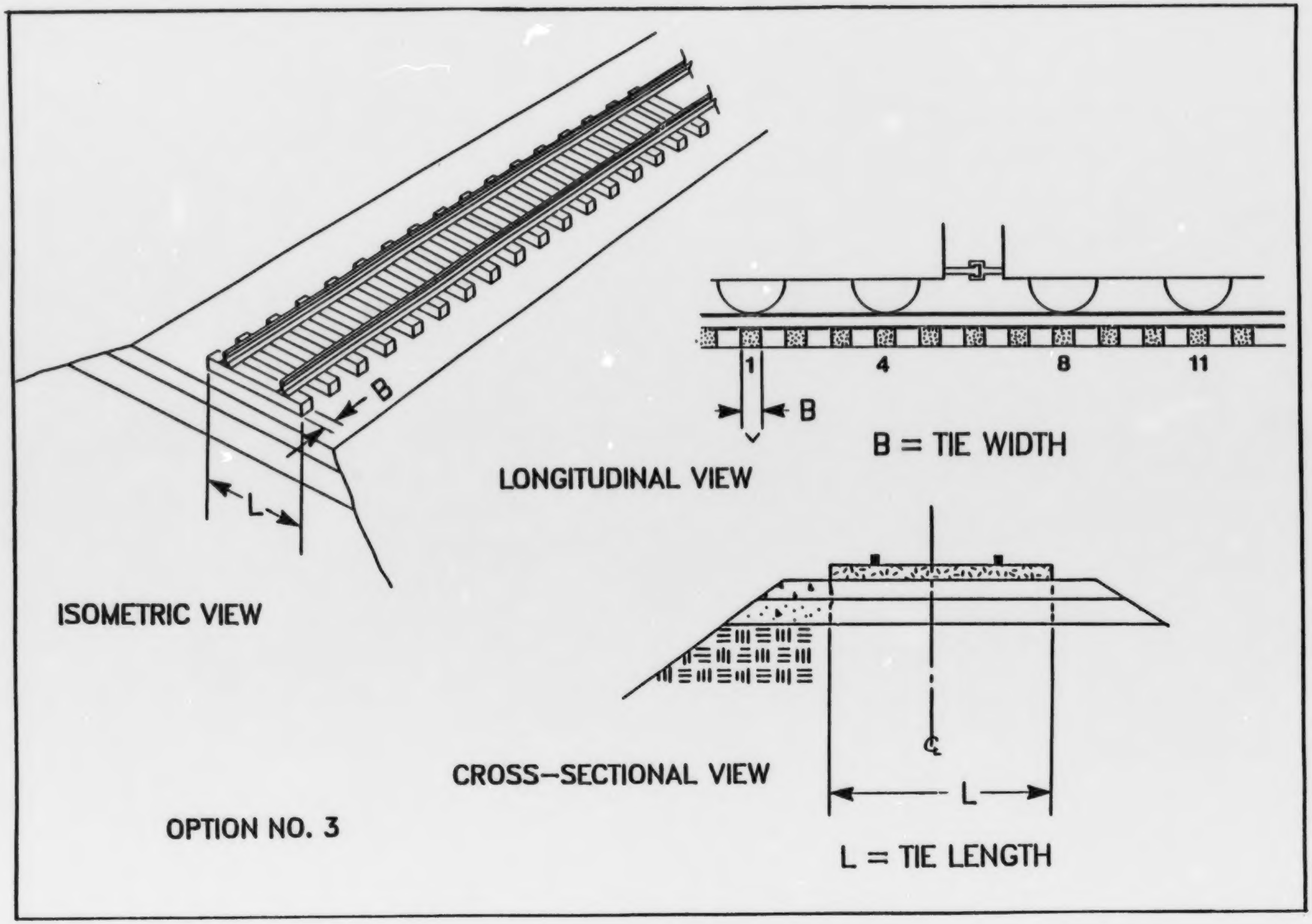

B
L
ISOMETRIC VIEW
1
4
8
11
B
B = TIE WIDTH
LONGITUDINAL VIEW
℄
L
CROSS-SECTIONAL VIEW
L = TIE LENGTH
OPTION NO. 3

Figure 5.4 Option 3 "Bearing Capacity Failure Geometry"

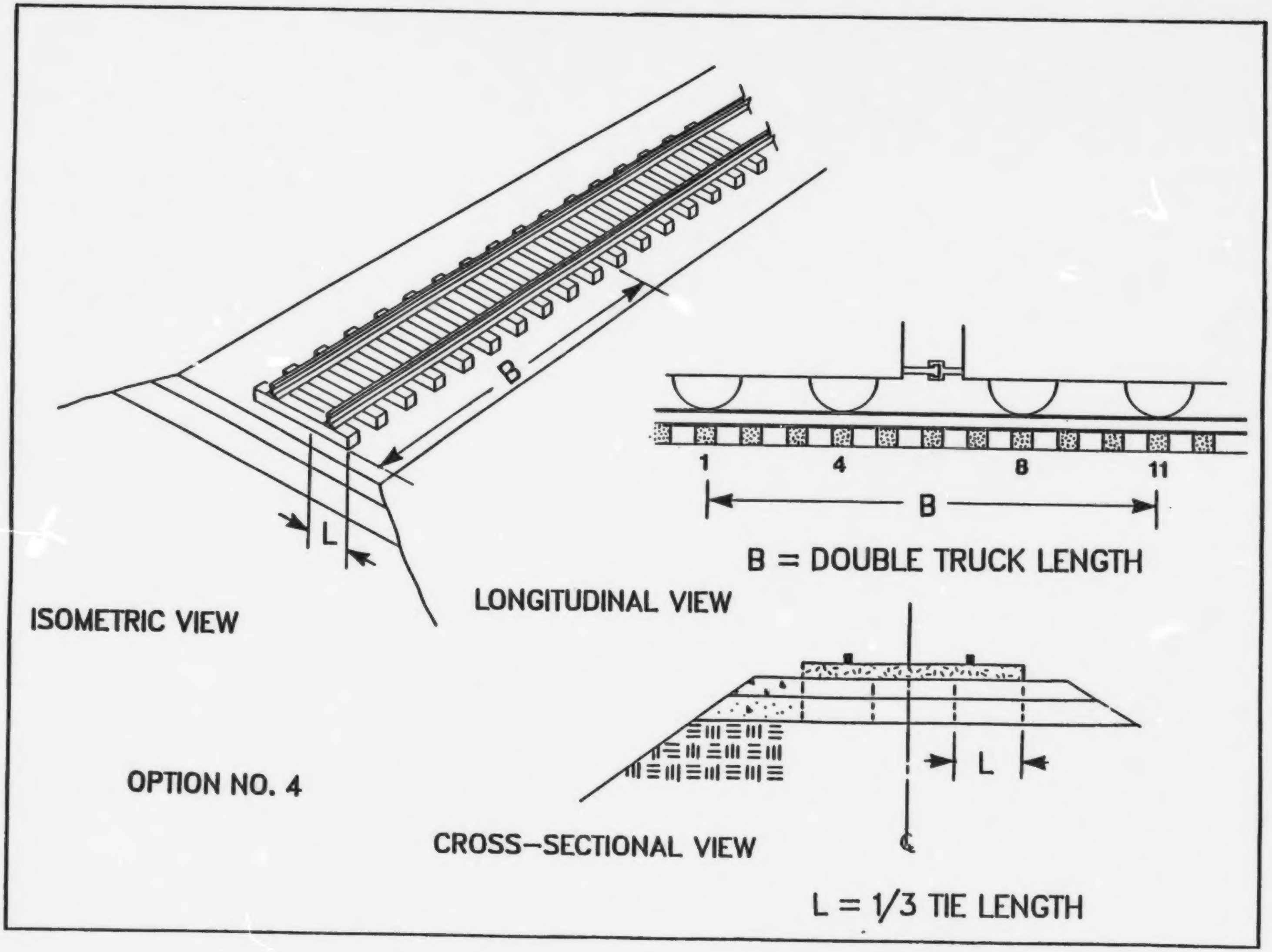

B
L
ISOMETRIC VIEW
1
4
8
11
B
B = DOUBLE TRUCK LENGTH
LONGITUDINAL VIEW
OPTION NO. 4
L
℄
CROSS-SECTIONAL VIEW
L = 1/3 TIE LENGTH

Figure 5.5 Option 4 "Bearing Capacity Failure Geometry"

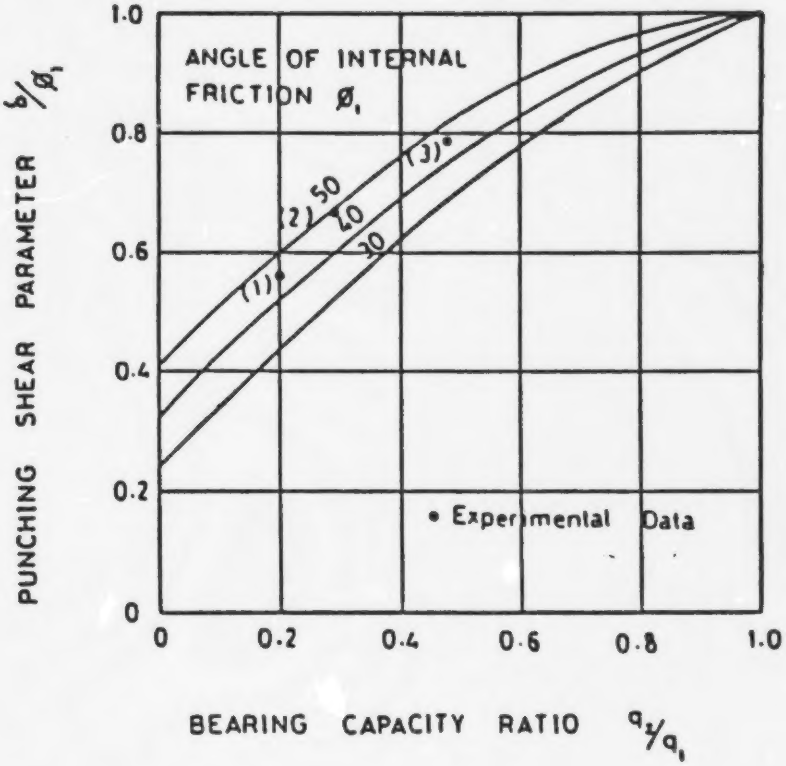
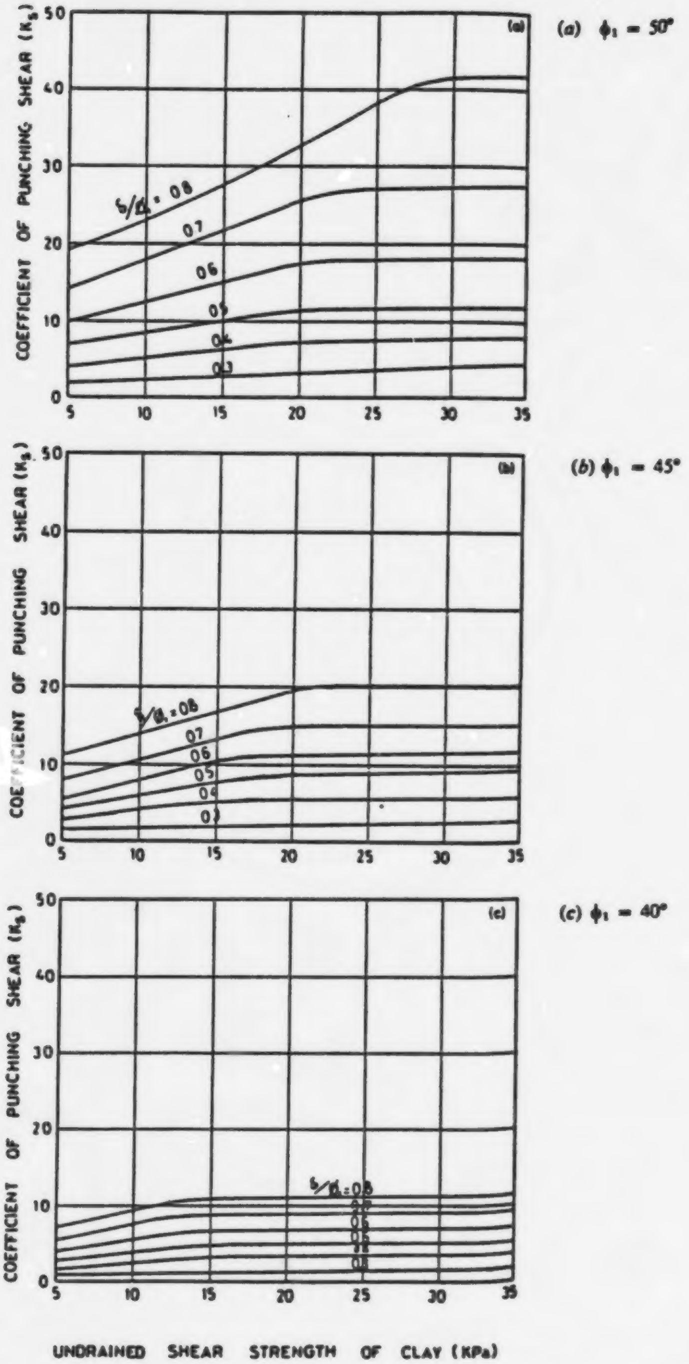


Figure 5.6 Determination of the Punching Shear Coefficient (Hanna and Meyerhof (3)



(a) ϕ_1 = 50°

(b) ϕ_1 = 45°

(c) ϕ_1 = 40°

Figure 5.7 Determination of the Punching Shear Coefficient (Hanna and Meyerhof (3))

the ballast are determined. The net bearing capacities for each of the subgrade and the ballast are determined and compared. A comparison of the bearing capacities determines the value of the punching shear coefficient from the charts published by Hanna and Meyerhof (i.e., the charts included as Figures 5.6 and 5.7 (Reference 3)).

Equations have been written to describe Figures 5.6 and 5.7. Therefore, the chart values become equations within the computer program. Consequently, the punching shear coefficient value becomes internal to the computer program and the user need not be concerned about choosing a value. The equations within the computer model are limited to an interpolation between the chart values and have not been extended for values outside the range published by Hanna and Meyerhof (3).

Once the punching shear coefficient has been determined, the bearing capacity equation by the Hanna and Meyerhof method (i.e., Equation [4] in the final report (1)) is used to determine the net bearing capacity for the ballast-subgrade system. The resulting information is printed to an output file.

5.3 Screen Displays and User Responses

The following few pages detail the user responses required to run the two example problems. Problem number one is a computation of the ultimate subgrade bearing capacity by Broms method (4) for Bearing Capacity Option 2 while problem two is a computation of the net bearing capacity of the ballast-subgrade system by the Hanna and Meyerhof method (3) for Bearing Capacity Option 3.

PROBLEM NO. 1:

CALCULATE BY BROMS METHOD THE BEARING CAPACITY FOR AN OPTION 2 "BEARING CAPACITY LOADING GEOMETRY". ASSUME A LOADED AREA, B × L, OF:

B = 0.864 m (1/3 OF 8'6" TIE LENGTH)

L = 1.78 m (MINIMUM - 70" DOUBLE TRUCK LENGTH).

BALLAST PARAMETERS:

DEPTH = 0.914 m (36")

$\gamma = 18$ kN/m^3

SUBGRADE PARAMETERS:

$c' = 5$ kPa

$\phi' = 25°$

$\phi^b = 15°$

$\gamma = 18$ kN/m^3

$(u_a - u_w) = 50$ kPa DESIGN VALUE CHOSEN

SOLVE USING THE COMPUTER PROGRAM "BEARING".

```
 BBBBBBB   EEEEEEEE   AAAAAA   RRRRRRR    IIIIII  NN    NN   GGGGGG
 BBBBBBBB  EEEEEEEE  AAAAAAAA  RRRRRRRR    II    NNN   NN  GGGGGGGG
 BB    BB  EE        AA    AA  RR    RR    II    NNN   NN  GG
 BB    BB  EE        AA    AA  RR    RR    II    NN N  NN  GG
 BBBBBBBB  EEEEEEEE  AAAAAAAA  RRRRRRRR    II    NN N  NN  GG  GGGG
 BB    BB  EEEEEEEE  AAAAAAAA  RRRRRRRR    II    NN  N NN  GG  GGGG
 BB    BB  EE        AA    AA  RR    RR    II    NN  N NN  GG    GG
 BBBBBBBB  EEEEEEEE  AA    AA  RR    RR    II    NN   NNN  GGGGGGGG
 BBBBBBB   EEEEEEEE  AA    AA  RR    RR  IIIIII  NN   NNN  GGGGGGGG

           BEARING is a computer program which computes the net
             bearing capacity of a ballast-subgrade system.

                      University of Saskatchewan
                          Saskatoon, Canada.
                            ( July 1988 )

DO YOU WISH TO COMPUTE THE NET BEARING CAPACITY BY BROMS METHOD
OR BY MEYERHOFS METHOD? (NOTE: MEYERHOFS METHOD IS ONLY APPLICABLE
TO SOFT CLAY SUBGRADES.)
(ENTER "BROM" OR "MEYERHOF")........BROM
------------------------------------------------------------------------
DRIVE & DIRECTORY for Input/Output files ?
( e.g., C:, C:\WORK\, or BLANK for current DIR )..........:
OUTPUT DATA FILE name ( Do not include .BRG )..............: BMETHOD

ENTER GENERAL COMMENTS THAT CAN BE ATTACHED TO
THE OUTPUT FILE. (MAXIMUM OF 70 CHARACTERS)

Example of Using Broms' Method for Bearing Capacity
```

```
INPUT THE GEOMETRY DATA B, L, D  WHERE:
B=WIDTH OF THE BEARING AREA (METERS)
L=LENGTH OF THE BEARING AREA (METERS) (NOTE: L=0 FOR A STRIP FOOTING)
D=DEPTH OF BALLAST (METERS)
(ENTER DATA IN THIS ORDER SEPARATED BY COMMAS OR SPACES.)

0.864  1.78  0.914

INPUT THE SUBGRADE DATA C, F, FB AND G WHERE:
C=EFFECTIVE COHESION (KPA)(i.e., c')
F=EFFECTIVE ANGLE OF INTERNAL FRICTION (DEGREES) (i.e., ø')
FB=ANGLE OF INTERNAL FRICTION W.R.T.MATRIC SUCTION (IE Ua-Uw) (DEGREES)
G=UNIT WEIGHT (KN/M^3)                    (i.e., ø^b)
(ENTER DATA IN THIS ORDER SEPARATED BY COMMAS OR SPACES.)

(5  25) (15)  18
      ø'   ø^b
INPUT THE SUBGRADE MATRIC SUCTION
(IE PORE AIR PRESSURE - PORE WATER PRESSURE) (KPA)

50

INPUT THE BALLAST G WHERE:
G=UNIT WEIGHT (KN/M^3)

18
```

```
              ***************INPUT DATA SUMMARY*****************
1. GEOMETRY
WIDTH OF AREA =         .864 METERS
LENGTH OF AREA =       1.780 METERS
DEPTH OF BALLAST =      .914 METERS

2. SUBGRADE DATA
EFFECTIVE COHESION =              5.00 KPA
EFFECTIVE FRICTION ANGLE =       25.00 DEGREES
EFFECTIVE B FRICTION ANGLE =     15.00 DEGREES
UNIT WEIGHT =                    18.00 KN/M^3

3. SUBGRADE MATRIC SUCTION
Ua-Uw =   50.00 KPA

4. BALLAST DATA
UNIT WEIGHT =                  18.00 KN/M^3

IS THE DATA SHOWN ABOVE SATISFACTORY?
ENTER "EDIT" TO EDIT OR "CONT" TO CONTINUE.......:CONT

2. SUBGRADE DATA
EFFECTIVE COHESION =              5.00 KPA
EFFECTIVE FRICTION ANGLE =       25.00 DEGREES
EFFECTIVE B FRICTION ANGLE =     15.00 DEGREES
UNIT WEIGHT =                    18.00 KN/M^3

3. SUBGRADE MATRIC SUCTION
Ua-Uw =   50.00 KPA

4. BALLAST DATA
UNIT WEIGHT =                  18.00 KN/M^3

IS THE DATA SHOWN ABOVE SATISFACTORY?
ENTER "EDIT" TO EDIT OR "CONT" TO CONTINUE.......:CONT

     ****** THE CALCULATIONS ARE COMPLETE ******

DO YOU WANT TO ANALYZE ANOTHER DATA SET OR QUIT THE PROGRAM?

ENTER "RESTART" OR "QUIT".

QUIT
Stop - Program terminated.

C:\MANUALS>
```

PROBLEM NO. 2:

CALCULATE BY THE HANNA AND MEYERHOF METHOD THE ULTIMATE BEARING CAPACITY FOR AN OPTION 3 "BEARING CAPACITY LOADING CONFIGURATION". ASSUME A TIE WIDTH OF 0.229m (9") AND ZERO BALLAST ABOVE THE BOTTOM OF THE TIE.

BALLAST PARAMETERS:

THICKNESS = 0.914m (36")
$\phi' = 45°$
$\gamma = 18\ kN/m^3$

SUBGRADE PARAMETERS:

$c' = 5\ kPa$
$\phi' = 15°$
$\phi^b = 15°$
$\gamma = 18\ kN/m^3$
$(u_a - u_w) = 25\ kPa$

SOLVE USING THE COMPUTER PROGRAM "BEARING".

```
                  University of Saskatchewan
                     Saskatoon, Canada.
                        ( July 1988 )

DO YOU WISH TO COMPUTE THE NET BEARING CAPACITY BY BROMS METHOD
OR BY MEYERHOFS METHOD? (NOTE: MEYERHOFS METHOD IS ONLY APPLICABLE
TO SOFT CLAY SUBGRADES.)
(ENTER "BROM" OR "MEYERHOF")........MEYERHOF
-----------------------------------------------------------------------------
DRIVE & DIRECTORY for Input/Output files ?
( e.g., C:, C:\WORK\, or BLANK for current DIR )...........:
OUTPUT DATA FILE name ( Do not include .BRG )..............: MEYER

ENTER GENERAL COMMENTS THAT CAN BE ATTACHED TO
THE OUTPUT FILE. (MAXIMUM OF 70 CHARACTERS)

Example of Subgrade Bearing Capacity by Meyerhof
```

```
INPUT THE GEOMETRY DATA B, D, H WHERE:
B=WIDTH OF THE BEARING AREA PLACED ON THE BALLAST (METERS)
D=DEPTH OF BURIAL (METERS)
H=BALLAST THICKNESS (METERS)
(ENTER DATA IN THIS ORDER SEPARATED BY COMMAS OR SPACES.)

0.229  0  0.914

INPUT THE SUBGRADE DATA C, F, FB AND G WHERE:
C=EFFECTIVE COHESION (KPA)
F=EFFECTIVE ANGLE OF INTERNAL FRICTION (DEGREES)
FB=ANGLE OF INTERNAL FRICTION W.R.T.MATRIC SUCTION (IE Ua-Uw) (DEGREES)
G=UNIT WEIGHT (KN/M^3)
(ENTER DATA IN THIS ORDER SEPARATED BY COMMAS OR SPACES.)
c'
5  15  15  18
      φ'     φb
INPUT THE SUBGRADE MATRIC SUCTION
(IE PORE AIR PRESSURE - PORE WATER PRESSURE) (KPA)

25

INPUT THE BALLAST PARAMETERS, F AND G WHERE
F=EFFECTIVE ANGLE OF INTERNAL FRICTION (DEGREES)
G=UNIT WEIGHT (KN/M^3)
(ENTER DATA IN THIS ORDER SEPARATED BY COMMAS OR SPACES.)

45  18
```

```
               ***************INPUT DATA SUMMARY*****************

1. GEOMETRY
WIDTH OF AREA =       .229 METERS
DEPTH OF BURIAL =     .000 METERS
DEPTH OF BALLAST =    .914 METERS

2. SUBGRADE DATA
EFFECTIVE COHESION =            5.00 KPA
EFFECTIVE FRICTION ANGLE =     15.00 DEGREES
EFFECTIVE B FRICTION ANGLE =   15.00 DEGREES
UNIT WEIGHT =                  18.00 KN/M^3

3. SUBGRADE MATRIC SUCTION
Ua-Uw =   25.00 KPA

4. BALLAST DATA
EFFECTIVE FRICTION ANGLE =   45.00 DEGREES
UNIT WEIGHT =                18.00 KN/M^3

IS THE DATA SHOWN ABOVE SATISFACTORY?
ENTER "EDIT" TO EDIT OR "CONT" TO CONTINUE.......:CONT
```

5.4 Typical Output Files

Two typical '.BRG' files are presented in Figures 5.8 and 5.9. Figure 5.8 illustrates the solution file for problem number one whereas Figure 5.9 illustrates the solution file for problem number two. Each output file includes an echo of the input data, a statement informing the user of the method used to compute the bearing capacity, pertinent calculated values prior to the computation of the ultimate bearing capacity, and the ultimate subgrade bearing capacity by Broms method (4) or the combined ballast-subgrade bearing capacity by the Hanna and Meyerhof method (3).

```
                    **************************************
                    *                                    *
                    *   BEARING CAPACITY OUTPUT FILE     *
                    *                                    *
                    **************************************

FILENAME: BMETHOD.BRG
METHOD: BROM
COMMENTS: Example of Using Broms' Method for Bearing Capacity

               ***************INPUT DATA SUMMARY*****************

1. GEOMETRY
WIDTH OF AREA =        .864 METERS
LENGTH OF AREA =      1.780 METERS
DEPTH OF BALLAST =     .914 METERS

2. SUBGRADE DATA
EFFECTIVE COHESION =           5.00 KPA
EFFECTIVE FRICTION ANGLE =    25.00 DEGREES
EFFECTIVE B FRICTION ANGLE =  15.00 DEGREES
UNIT WEIGHT =                 18.00 KN/M^3

3. SUBGRADE MATRIC SUCTION
Ua-Uw =   50.00 KPA

4. BALLAST DATA
UNIT WEIGHT =                18.00 KN/M^3

THE BROMS APPROACH WAS USED FOR THE CALCULATION OF THE NET BEARING CAPACITY

SUBGRADE BEARING CAPACITY FACTORS
     Nq =  10.66
     Nc =  20.72
     Ng =   6.76

TOTAL COHESION =  18.40 KPA

SUBGRADE SHAPE FACTORS
     Sc =   1.25
     Sq =   1.25
     Sg =    .81

NET BEARING CAPACTIY =   738.00 KPA
```

c'

ϕ'

ϕ^b

$c = c' + (u_a - u_w) \tan \phi^b$

Figure 5.8 Bearing Capacity Program Output File

```
***************************************
*                                     *
*   BEARING CAPACITY OUTPUT FILE      *
*                                     *
***************************************

FILENAME: MEYER.BRG
METHOD: MEYERHOF
COMMENTS: Example of Subgrade Bearing Capacity by Meyerhof


               ***************INPUT DATA SUMMARY*****************

1. GEOMETRY
WIDTH OF AREA =         .229 METERS
DEPTH OF BURIAL =       .000 METERS
DEPTH OF BALLAST =      .914 METERS
                                          c'
2. SUBGRADE DATA                               φ'
EFFECTIVE COHESION =               5.00 KPA
EFFECTIVE FRICTION ANGLE =         15.00 DEGREES  φb
EFFECTIVE B FRICTION ANGLE =       15.00 DEGREES
UNIT WEIGHT =                      18.00 KN/M^3

3. SUBGRADE MATRIC SUCTION
Ua-Uw =    25.00 KPA

4. BALLAST DATA
EFFECTIVE FRICTION ANGLE =     45.00 DEGREES
UNIT WEIGHT =                  18.00 KN/M^3

THE MEYERHOLF APPROACH WAS USED FOR THE CALCULATION OF THE NET BEARING CAPACIT

SUBGRADE BEARING CAPACITY FACTORS
      Nq =    3.94
      Nc =   10.98
      Ng =    1.18           c = c' + (ua - uw) tan φb

TOTAL COHESION =  11.70 KPA

BALLAST BEARING CAPACITY =    413.88 KPA

SUBGRADE BEARING CAPACITY =    130.85 KPA

NET BEARING CAPACTIY =   831.80 KPA
```

Figure 5.9 Bearing Capacity Program Output File

COMPARE USER'S MANUAL

6.0 User's Manual for the COMPARE Computer Program

The computer program, COMPARE, was developed at the University of Saskatchewan solely for the purpose of creating bearing capacity factor of safety design charts (i.e., charts such as those presented in the final report (1)). COMPARE serves no purpose for the user who does not wish to use the bearing capacity design approach to compare the average stress distributions to the ultimate bearing capacity of the railway subgrade system.

6.1 Introduction to the COMPARE Computer Program

The program asks the user to input the desired files for comparison, checks that the files are compatible for the bearing capacity approach comparison, and prints the combined files and factor of safety to an output file.

6.2 Description of the COMPARE Computer Program

Figure 6.1 presents a general algorithm for the computer program COMPARE. Figure 1.1 illustrates the significance of the computer program COMPARE to the development of the bearing capacity factor of safety design charts.

Upon program execution, the screen displays the title of the computer program, COMPARE. The user is asked to input the drive and directory for the input and output files, the input STRESS data file name having the suffix '.STR', the input BEARING data file name having the suffix '.BRG', and the desired name for the COMPARE output file having the suffix '.CPE'.

The BEARING file is checked to determine if the bearing capacity geometry corresponds to the approximate range of dimensions expected for the Stress Averaging Technique Option in the STRESS file. If the two files are not compatible, the user is informed of the error and given the opportunity to request the comparison of alternate data files.

If the two files input for comparison are compatible, the data files are combined into a '.CPE' (i.e., COMPARE output file) and the original '.STR' and '.BRG' files are erased. The bearing capacity is divided by the average stress to determine the bearing capacity factor of safety and the resulting value is written to the output file. The user may then request to run COMPARE again or exit from the program.

1) Display name of program.

2) Input drive and directory, name of STRESS data input file, name of BEARING data input file, name of COMPARE output file to be created with suffix '.CPE'.

3) Check that input files are compatible.

4) Concatenate STRESS and BEARING files into COMPARE file.

5) Delete original STRESS and BEARING files.

6) Compute bearing capacity factr of safety. Write results to COMPARE file.

7) Ask if user wishes to start over. If yes, start over at item 1). If not, exit from the program.

Figure 6.1 General Algorithm for COMPARE Computer Program

6.3 Screen Displays and User Responses

The next few pages show the screen displays and user responses for two example problems. The first problem compares the results in the file OPTION2.STR to the results in the file BMETHOD.BRG. OPTION2.STR was created as an example problem in Section 4 whereas BMETHOD.BRG was created as an example problem in Section 5. The second example problem compares the results in the file OPTION3.STR to the results in MEYER.BRG. Again, OPTION3.STR was created as an example problem in Section 4 while MEYER.BRG was created as an example problem in Section 5.

```
CCCCCCCC   OOOOOO    MM      MM   PPPPPPP     AAAAAA    RRRRRRR    EEEEEEEE
CCCCCCCC  OOOOOOOO   MMM    MMM   PPPPPPPP   AAAAAAAA   RRRRRRRR   EEEEEEEE
CC        OO    OO   MM MM MM MM  PP     PP  AA    AA   RR     RR  EE
CC        OO    OO   MM      MM   PP     PP  AA    AA   RR     RR  EE
CC        OO    OO   MM      MM   PPPPPPPP   AAAAAAAA   RRRRRRRR   EEEEEEEE
CC        OO    OO   MM      MM   PPPPPPPP   AAAAAAAA   RRRRRRRR   EEEEEEEE
CC        OO    OO   MM      MM   PP         AA    AA   RR     RR  EE
CCCCCCCC  OOOOOOOO   MM      MM   PP         AA    AA   RR     RR  EEEEEEEE
CCCCCCCC   OOOOOO    MM      MM   PP         AA    AA   RR     RR  EEEEEEEE

          COMPARE is a computer program which computes a bearing
      capacity factor using data computed with BEARING and STRESS.

                       University of Saskatchewan
                           Saskatoon, Canada.
                              ( Aug. 1988 )

--------------------------------------------------------------------------------
DRIVE & DIRECTORY for Input/Output files ?
( e.g., C:, C:\WORK\, or BLANK for current DIR )............:

                              ( Aug. 1988 )

--------------------------------------------------------------------------------
DRIVE & DIRECTORY for Input/Output files ?
( e.g., C:, C:\WORK\, or BLANK for current DIR )............:
STRESS DATA FILE name ( Do not include .STR )................: OPTION2
BEARING DATA FILE name ( Do not include .BRG )..............: BMETHOD

--------------------------------------------------------------------------------
OUTPUT DATA FILE name ( Do not include .CPE )..............: BCFBROM

********* OPTION # 2 USED FOR STRESS CALCULATIONS *********


=======================================================================
        CALCULATED BEARING CAPACITY FACTOR=    11.23
=======================================================================


DO YOU WANT TO ANALYZE ANOTHER DATA SET OR QUIT THE PROGRAM?

ENTER "RESTART" OR "QUIT".....: RESTART
```

```
DO YOU WANT TO ANALYZE ANOTHER DATA SET OR QUIT THE PROGRAM?

ENTER "RESTART" OR "QUIT".....: RESTART
----------------------------------------------------------------------------
DRIVE & DIRECTORY for Input/Output files ?
( e.g., C:, C:\WORK\, or BLANK for current DIR )............:
STRESS DATA FILE name ( Do not include .STR )...............: OPTION3
BEARING DATA FILE name ( Do not include .BRG )..............: MEYER

----------------------------------------------------------------------------
OUTPUT DATA FILE name ( Do not include .CPE )...............: BCFMEYER

********* OPTION # 3 USED FOR STRESS CALCULATIONS *********


=====================================================================
        CALCULATED BEARING CAPACITY FACTOR=    3.28
=====================================================================


DO YOU WANT TO ANALYZE ANOTHER DATA SET OR QUIT THE PROGRAM?

ENTER "RESTART" OR "QUIT".....: QUIT
```

6.4 Typical Results

Figures 6.2 and 6.3 depict example output files for each of the two examples discussed in section 6.3. An output file consists of the concatenation of the BEARING output file and the STRESS output file, plus the computed factor of safety.

```
                  ***********************************
                  *                                 *
                  *        COMPARE OUTPUT FILE      *
                  *                                 *
                  ***********************************

       This file is a summary of the output files created by
                 the programs STRESS and BEARING.
===================================================================
                  SUMMARY OF OUTPUT FROM PROGRAM STRESS
===================================================================

 FILENAME: OPTION2.STR
 INPUT FILE: E1035T36.OGT
 COMMENTS: Averaged Stress for Option 2 on E1035T36

 NUMBER OF AXLE LOADS: 4
 AXLE LOAD = 219.73 kN ON TIE NO.  1
 AXLE LOAD = 219.73 kN ON TIE NO.  4
 AXLE LOAD = 219.73 kN ON TIE NO.  8
 AXLE LOAD = 219.73 kN ON TIE NO. 11

      OPTION NO. = 2     AVG.STRESS =   65.74 kPa
  Averaged stress is a SUBGRADE SURFACE stress
  Compare to BROMS approach

===================================================================
                  SUMMARY OF OUTPUT FROM PROGRAM BEARING
===================================================================

 FILENAME: BMETHOD.BRG
 METHOD: BROM
 COMMENTS: Example of Using Broms' Method for Bearing Capacity

              ***************INPUT DATA SUMMARY*****************

 1. GEOMETRY
 WIDTH OF AREA =        .864 METERS
 LENGTH OF AREA =      1.780 METERS
 DEPTH OF BALLAST =     .914 METERS

 2. SUBGRADE DATA
 EFFECTIVE COHESION =             5.00 KPA
 EFFECTIVE FRICTION ANGLE =      25.00 DEGREES
 EFFECTIVE B FRICTION ANGLE =    15.00 DEGREES
 UNIT WEIGHT =                   18.00 KN/M^3

 3. SUBGRADE MATRIC SUCTION
 Ua-Uw =   50.00 KPA

 4. BALLAST DATA
 UNIT WEIGHT =                 18.00 KN/M^3

 THE BROMS APPROACH WAS USED FOR THE CALCULATION OF THE NET BEARING CA

 SUBGRADE BEARING CAPACITY FACTORS
      Nq =  10.66
      Nc =  20.72
      Nq =   6.76

 TOTAL COHESION =  18.40 KPA

 SUBGRADE SHAPE FACTORS
      Sc =   1.25
      Sq =   1.25
      Sg =    .81

 NET BEARING CAPACTIY =   738.00 KPA


===================================================================
                  CALCULATED BEARING CAPACITY FACTOR
===================================================================

 BEARING CAPACITY FACTOR =   11.23
```

Figure 6.2   COMPARE Program Output File

```
                    ***********************************
                    *                                 *
                    *       COMPARE OUTPUT FILE       *
                    *                                 *
                    ***********************************

        This file is a summary of the output files created by
                   the programs STRESS and BEARING.
*******************************************************************
                SUMMARY OF OUTPUT FROM PROGRAM STRESS
*******************************************************************


 FILENAME: OPTION3.STR
 INPUT FILE: E1035T36.OGT
 COMMENTS: Averaged Stress for Option 3 on E1035T36


 NUMBER OF AXLE LOADS: 4
 AXLE LOAD = 219.73 kN ON TIE NO.  1
 AXLE LOAD = 219.73 kN ON TIE NO.  4
 AXLE LOAD = 219.73 kN ON TIE NO.  8
 AXLE LOAD = 219.73 kN ON TIE NO. 11

    OPTION NO. = 3     AVG.STRESS =  253.69 kPa
  Averaged stress is a BALLAST SURFACE stress
  Compare to MEYERHOF and HANNA approach


*******************************************************************
                SUMMARY OF OUTPUT FROM PROGRAM BEARING
*******************************************************************


 FILENAME: MEYER.BRG
 METHOD: MEYERHOF
 COMMENTS: Example of Subgrade Bearing Capacity by Meyerhof

             ***************INPUT DATA SUMMARY*****************

 1. GEOMETRY
 WIDTH OF AREA =        .229 METERS
 DEPTH OF BURIAL =      .000 METERS
 DEPTH OF BALLAST =     .914 METERS

 2. SUBGRADE DATA
 EFFECTIVE COHESION =              5.00 KPA
 EFFECTIVE FRICTION ANGLE =       15.00 DEGREES
 EFFECTIVE B FRICTION ANGLE =     15.00 DEGREES
 UNIT WEIGHT =                    18.00 KN/M^3

 3. SUBGRADE MATRIC SUCTION
 Ua-Uw =   25.00 KPA

 4. BALLAST DATA
 EFFECTIVE FRICTION ANGLE =   45.00 DEGREES
 UNIT WEIGHT =                18.00 KN/M^3

 THE MEYERHOLF APPROACH WAS USED FOR THE CALCULATION OF THE NET BEARIN

 SUBGRADE BEARING CAPACITY FACTORS
      Nq =   3.94
      Nc =  10.98
      Ng =   1.18

 TOTAL COHESION =  11.70 KPA

 BALLAST BEARING CAPACITY =   413.88 KPA

 SUBGRADE BEARING CAPACITY =   130.85 KPA

 NET BEARING CAPACTIY =   831.80 KPA


*******************************************************************
                 CALCULATED BEARING CAPACITY FACTOR
*******************************************************************


 BEARING CAPACITY FACTOR =    3.28
```

Figure 6.3   COMPARE Program Output File

7.0 CONCLUSIONS

This report describes the computer programs, GEOTRACK, GEOPLOT, STRESS, BEARING and COMPARE. The programs are used together to develop bearing capacity factor of safety design charts for railway track subgrade systems in the final report, entitled, "The Development of Bearing Capacity Design Charts for Track Systems" (1). The programs GEOTRACK and GEOPLOT may be used independently of a bearing capacity approach to railway subgrade design for modelling and graphing the stress distribution beneath a tie-track system. Similarly, the computer program BEARING may be used independently of the other programs to predict the bearing capacity of a railway subgrade system. The computer packages, STRESS and COMPARE have been developed exclusively for use in a bearing capacity design approach to railway subgrades as described in the final report (1).

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APPENDIX A

APPENDIX A

The Calculation of Equivalent Triaxial Stresses

The calculation of equivalent triaxial stresses is done by subroutine **TRIAXL**. In this program, the geostatic earth pressure is calculated first. The additional surcharge of the rail and tie is included in the initial stresses.

The initial vertical stress is the sum of the vertical overburden pressure and the additional surcharge. The initial horizontal stresses are related to the initial geostatic vertical stresses using the K_o values. The octahedral stresses consider the geostatic and the incremental stresses. The incremental stresses are induced by the vehicle loads.

The purpose of considering octahedral stresses is to account for the three-dimensionality of the problem, and to obtain an easier physical interpretation of the three-dimensional system by considering the applied stresses to be divided into those causing volume change and those causing shear distortion. In addition, this will allow simulation of the field stresses with laboratory cyclic triaxial tests. The octahedral normal stress, σ_{oct}, is a function of the first invariant of stresses I_1, whereas the octahedral shear stress, τ_{oct}, is a function of the first and second invariants I_1 and I_2, where the invariants are:

$$I_1 = \sigma_{xx} + \sigma_{yy} + \sigma_{zz},$$

$$I_2 = \sigma_{xx}\sigma_{yy} + \sigma_{xx}\sigma_{zz} + \sigma_{yy}\sigma_{zz} - \sigma_{xy}^2 - \sigma_{xz}^2 - \sigma_{yz}^2,$$

$$\sigma_{oct}\ (\text{field}) = \frac{I_1}{3} \quad \text{, and}$$

$$\tau_{oct}\ (\text{field}) = \sqrt{-\frac{2}{3}\left(I_2 - \frac{I_1^2}{3}\right)} \quad .$$

The stress paths produced in the field due to the imposition of wheel loads can be simulated in the laboratory using cyclic or repeated triaxial tests. For a triaxial compression test with confining pressure equal to σ_3 and a repeated deviator stress equal to $\sigma_1 - \sigma_3$, the corresponding octahedral stresses are:

$$\sigma_{oct}\ (\text{triaxial}) = \frac{\sigma_1 + 2\sigma_3}{3} \quad \text{, and}$$

$$\tau_{oct}\ (\text{triaxial}) = \frac{\sqrt{2}}{3}(\sigma_1 - \sigma_3) \quad .$$

Set:

$$\sigma_{oct}\ (\text{field}) = \sigma_{oct}\ (\text{triaxial}), \text{ and}$$

$$\tau_{oct}\ (\text{field}) = \tau_{oct}\ (\text{triaxial}).$$

Solve for σ_1 and σ_3:

$$\sigma_1 \text{ (triaxial)} = \sigma_{oct} \text{ (field)} + \sqrt{2}\, \tau_{oct} \text{ (field), and}$$

$$\sigma_3 \text{ (triaxial)} = \sigma_{oct} \text{ (field)} - \frac{1}{\sqrt{2}}\, \tau_{oct} \text{ (field).}$$

Also:

$$p_o = \frac{\sigma_v(1 + K_o)}{2} , \qquad p_{max} = \frac{\sigma_1 + \sigma_3}{2} ,$$

$$q_o = \frac{\sigma_v(1 - K_o)}{2} , \text{ and } \quad q_{max} = \frac{\sigma_1 - \sigma_3}{2} .$$

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